Present Results and Near Term Goals of the Cryogenic Dark Matter Search

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(For the CDMS collaboration)

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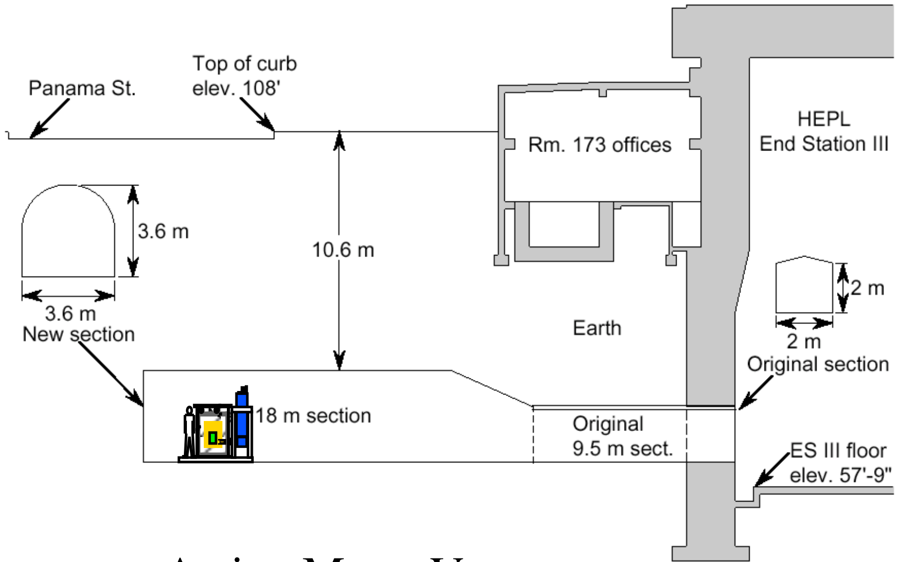
Talk Overview

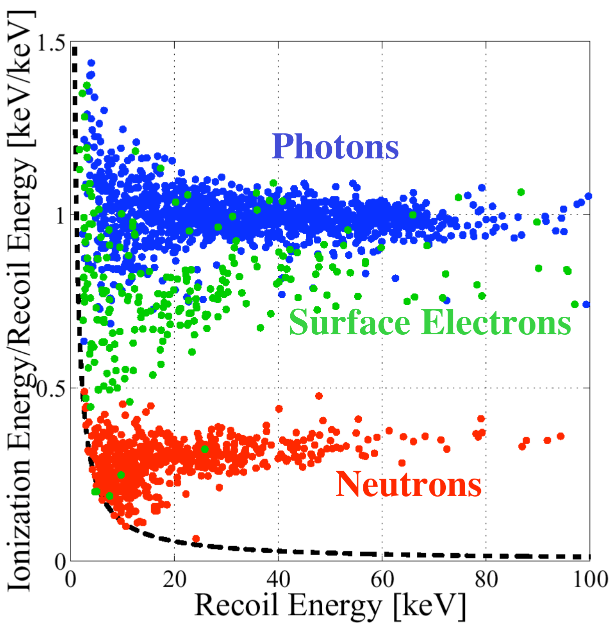
- CDMS I
  - Experiment setup and detector intro
  - Improved analysis of 1999 data and update to previous result (PRL 2000)
- CDMS II
  - Site, setup, and new detector technology
  - Perfomance specs for (detectors + shielding) and resulting sensitivity
- Transition to CDMS II: SUF Run 21 (11/01 to 6/02)
  - Goals of run; Have they been achieved?
  - Preliminary physics analysis
- Summary

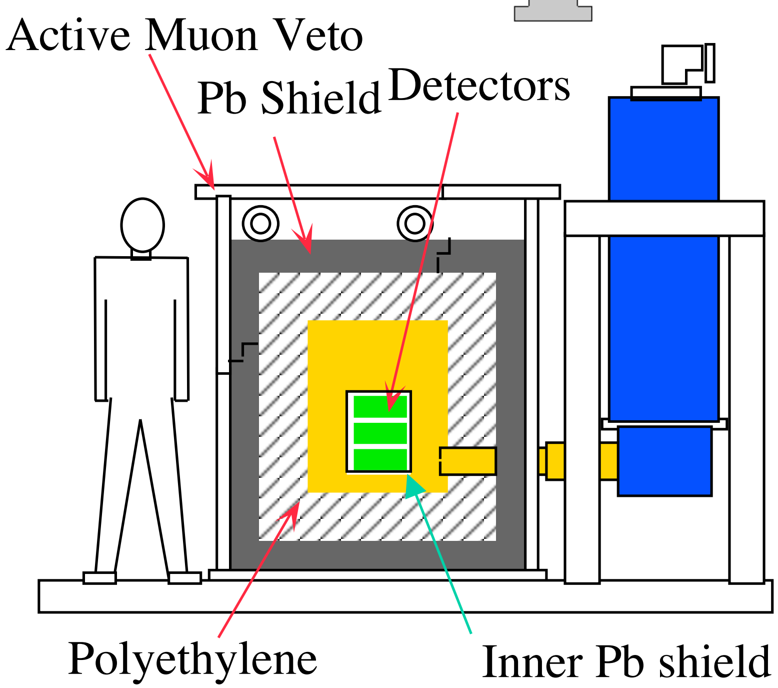
CDMS I

Main Principles

- **Stanford Underground Facility (SUF) at 17 mwe of rock**
- **Active scintillator + gamma and neutron shielding + radio-pure inner volume**
- **Event-by-event nuclear recoil discrimination**







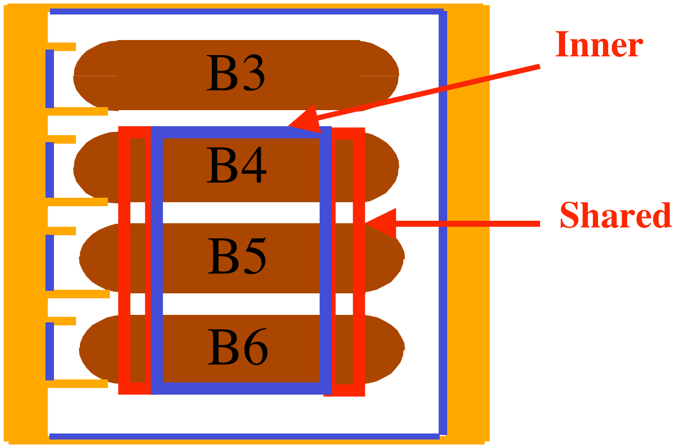
1999 Physics Run

- **Four 165 g Ge Berkeley Large Ionization and Phonon detectors used**
- **Results first published in**

  R. Abusaidi *et.al.* Phys. Rev. Lett. 84 5699 (2000)

Improved Analysis

1. **Increased fiducial volume**
   - **10.6 kg-days to 15.8 kg-days**
   - **23 Ge singles, 4 Ge multiples, 4 NR candidates in Si from 1998 data run**
2. **Larger allowance for contamination of 1998 Si events by electrons**



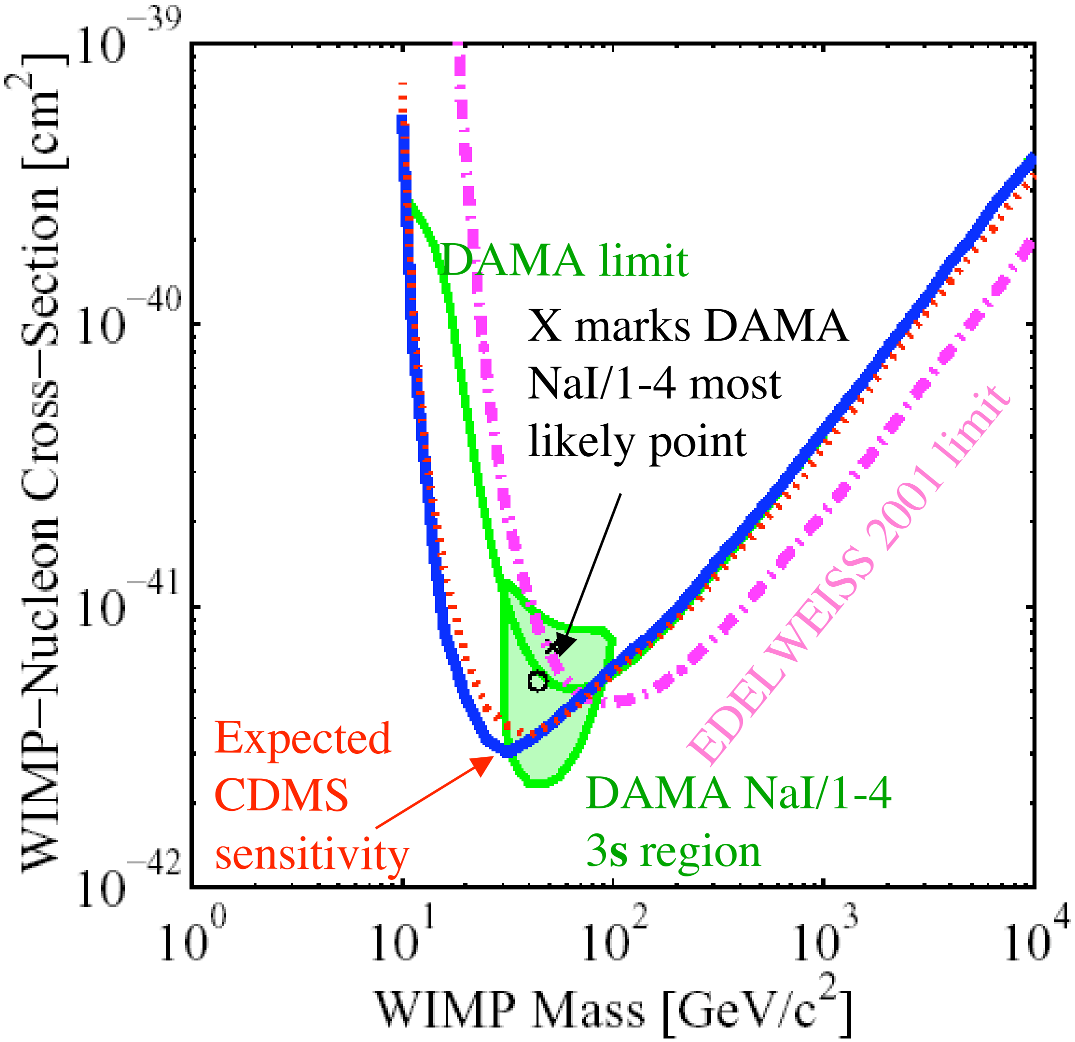
•These two changes result in slightly weaker WIMP upper limit than before

•Paper with discussion of new analysis, systematics, and neutron background accepted for publication in PRD.

•Astro-ph/0203500v3

CDMS Upper Limits for WIMP detection

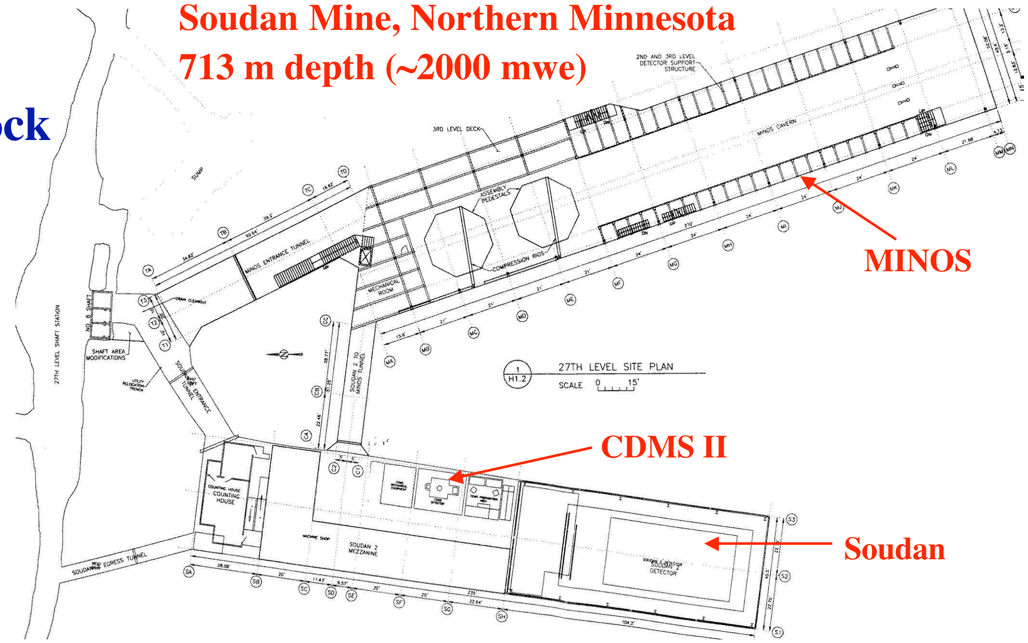
90% CL upper limits assuming standard halo, A^2 scaling

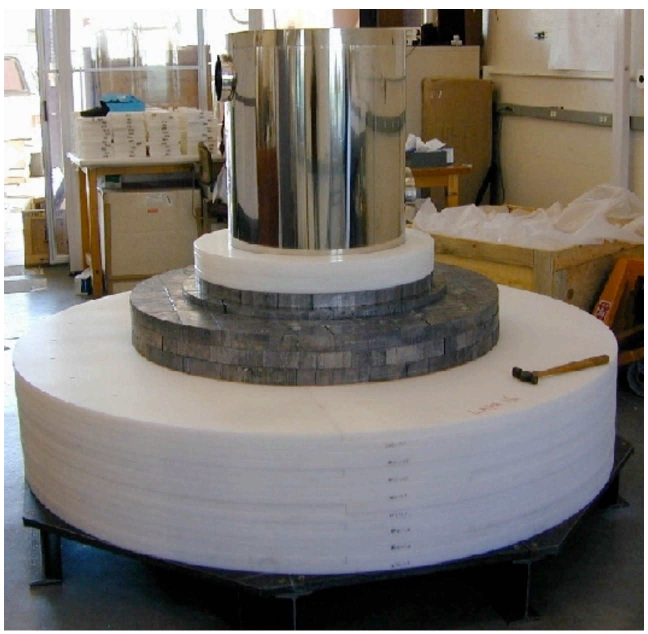


- **CDMS results consistent with all observed 'WIMP' events being neutrons.**
- **CDMS provided the most constraining upper limit of any experiment for WIMPs with 10-70 GeV mass in 2001.**
- **EDELWEISS 2002 limit better above 35 GeV.**
- **Rules out DAMA NaI/1-4 (NaI/0-4, circle) most likely point at >99.9% CL (for standard halo and spin-independent cross-section).**
- **Likelyhood test between published DAMA modulation and CDMS, show incompatibility > 99.99%**
- **Edelweiss is in agreement**

CDMS II

- Muon flux reduced by > factor 30,000
- Muon-induced neutron rate in rock smaller by factor ~1000
- WIMP candidate event rate of 0.01/kg/day assuming reasonable background rates and nominal detector performance





•60 days of running with first detector tower will give ~ factor 5 improvement over present CDMS sensitivity

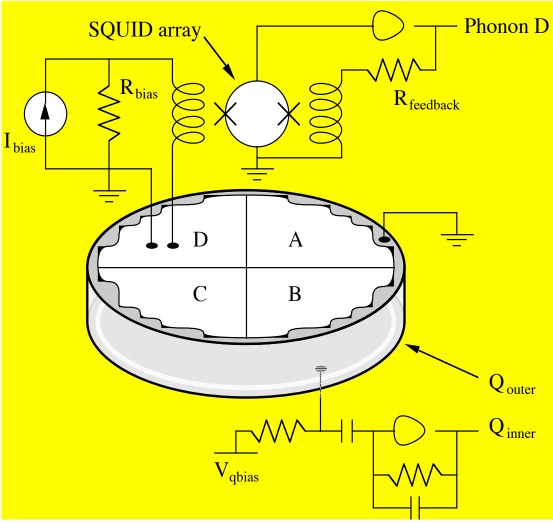
•With 7 towers of 6 detectors each, factor 100 improvement over present experimental limits is expected ultimately

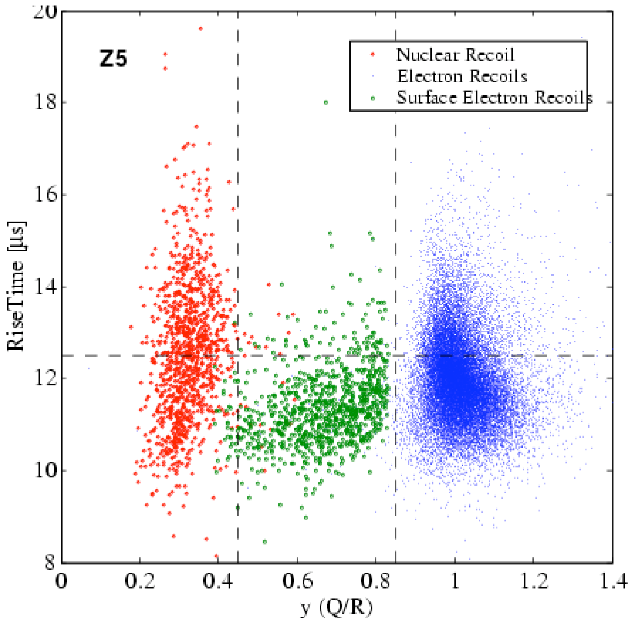
•A new detector technology (ZIP detectors) will be used in CDMS II to achieve above goals

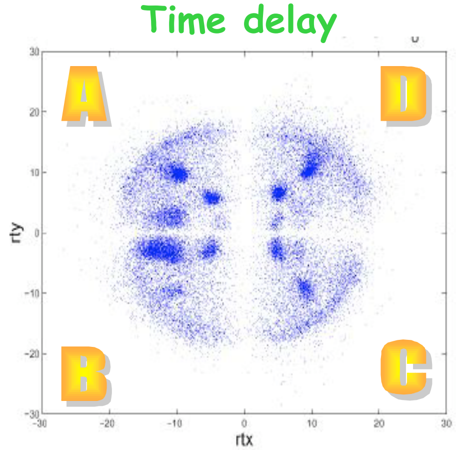
ZIP Detectors

- Z-sensitive Ionization and Phonon Detectors
- Ionization measurement same as before
- Athermal phonon measurement (faster than BLIP technology)

- **Technology involves Transition Edge Sensors (TES), trapping of quasiparticles, and SQUID arrays**
- **Position information (xy and z) due to collecting phonons on faster time scale**

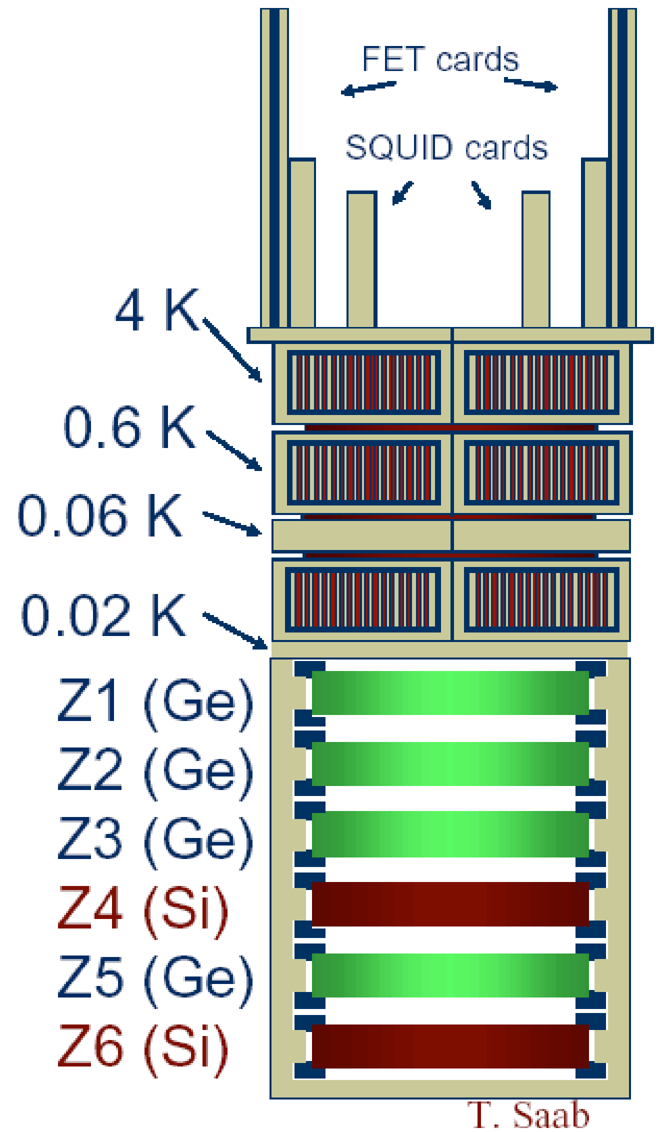






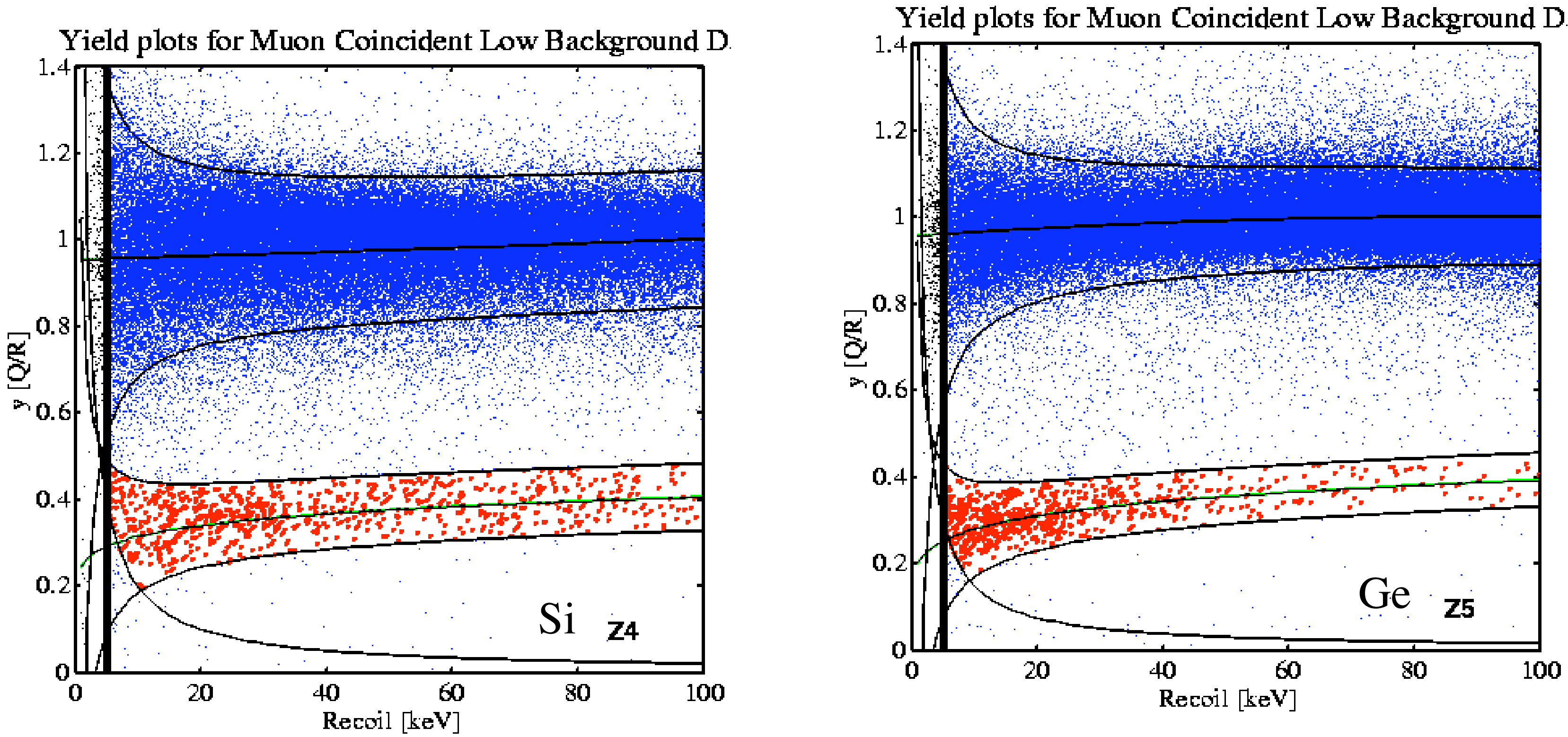
SUF Run 21

- **Uses Tower 1 of CDMS II**
  - **4 Ge (250 g each) and 2 Si (100 g each) detectors**
  - **~equal exposures at 3V and 6V bias, each with ~x2 1999 exposure**
- **More polyethylene installed inside ancient lead**
  - **Should reduce limiting neutron background by x 2.3**
- **Goals**
  - **Check neutron background hypothesis from Run 19 (1999 run). Having both Ge and Si is useful.**
  - **Check whether ZIP detector performance and contamination.**
- **Only the 3 V data has been analyzed so far**
- **Following plots with 85% inner fiducial volume cut**



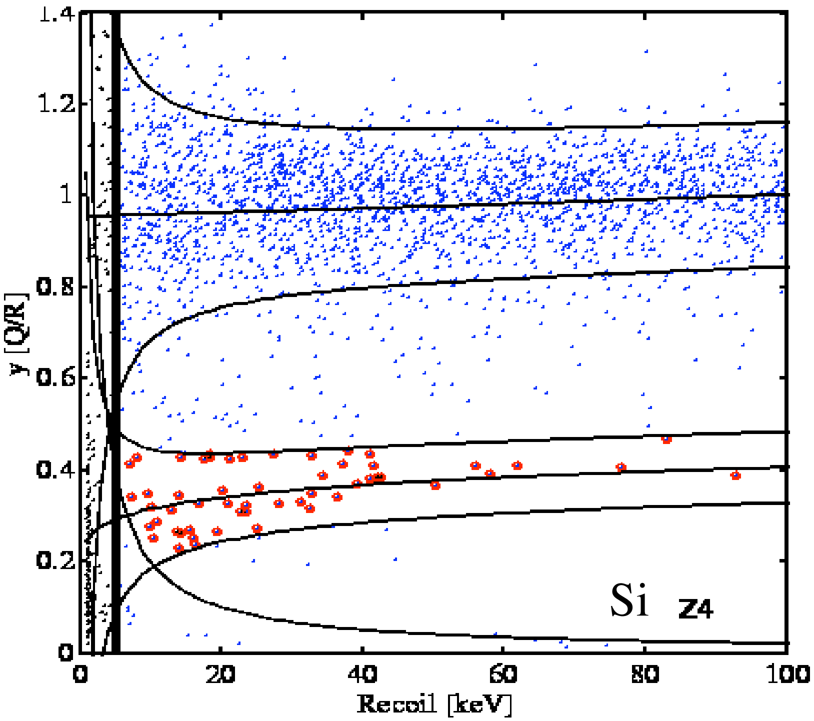
CDMS II Tower1 at SUF (1)

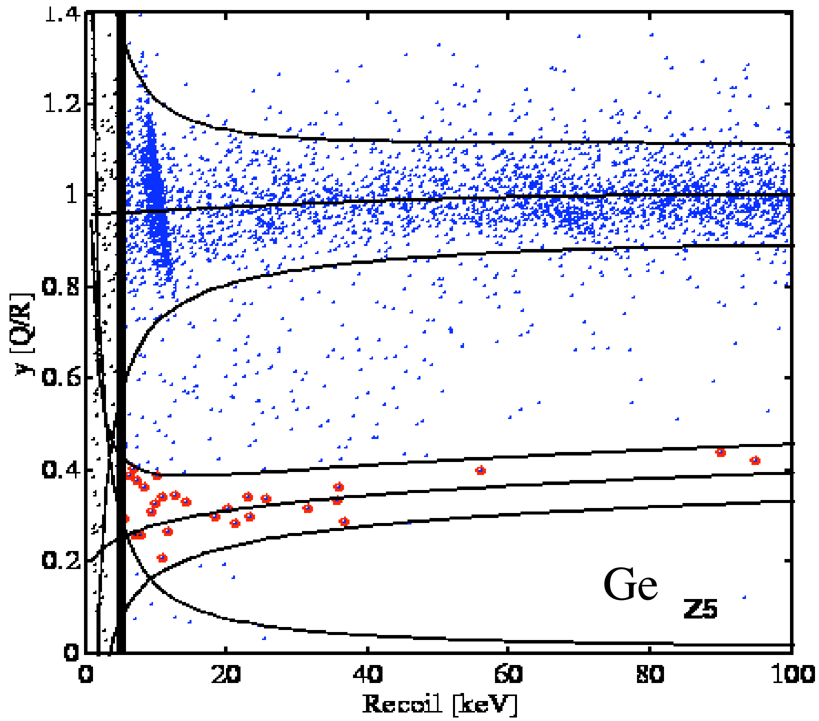
- –Muon Coincident Data
  - –Gamma background band is the dominant feature
  - –Muon coincident neutrons populate the nuclear recoil band



CDMS II Tower1 at SUF (2)

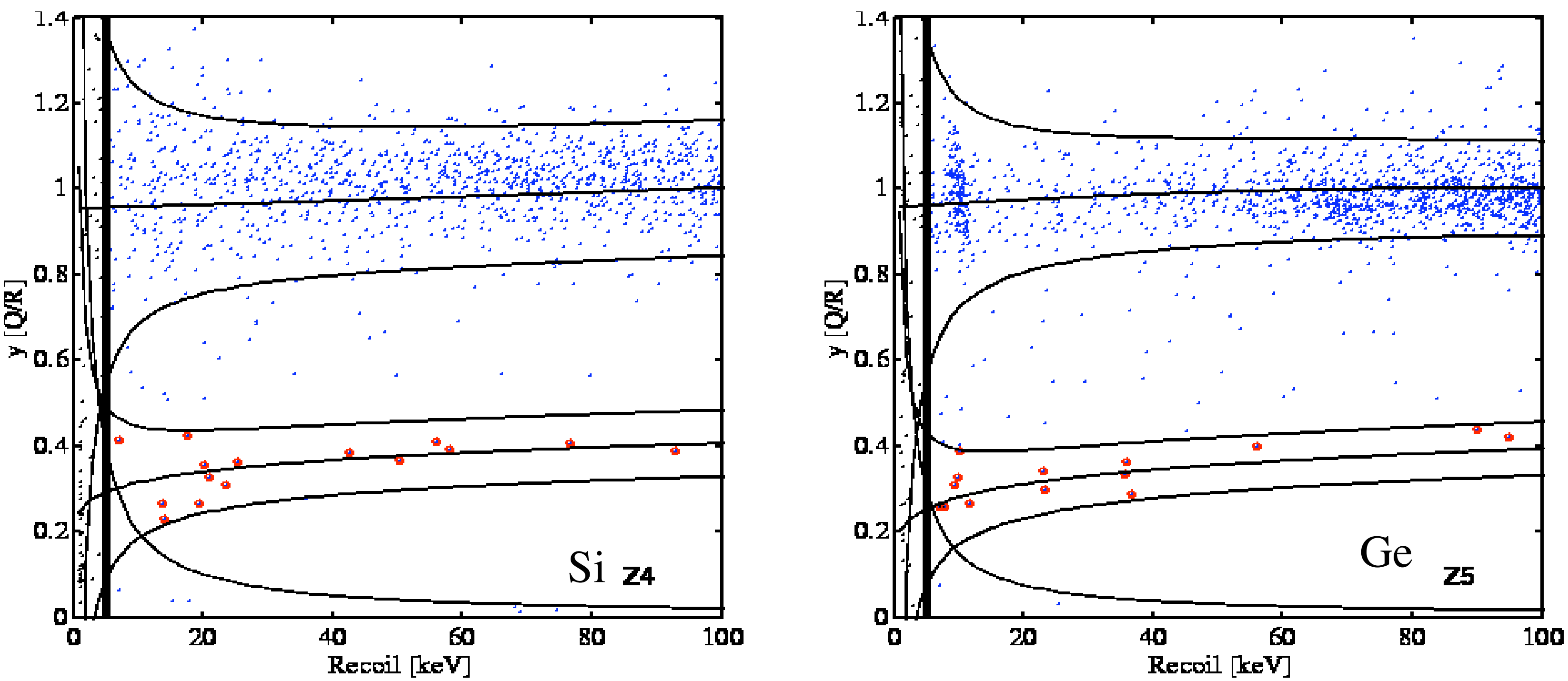
– Muon Anti-Coincident Data
  – All events
  – A sizeable population of nuclear recoil events
  – A number of '*in between*' events





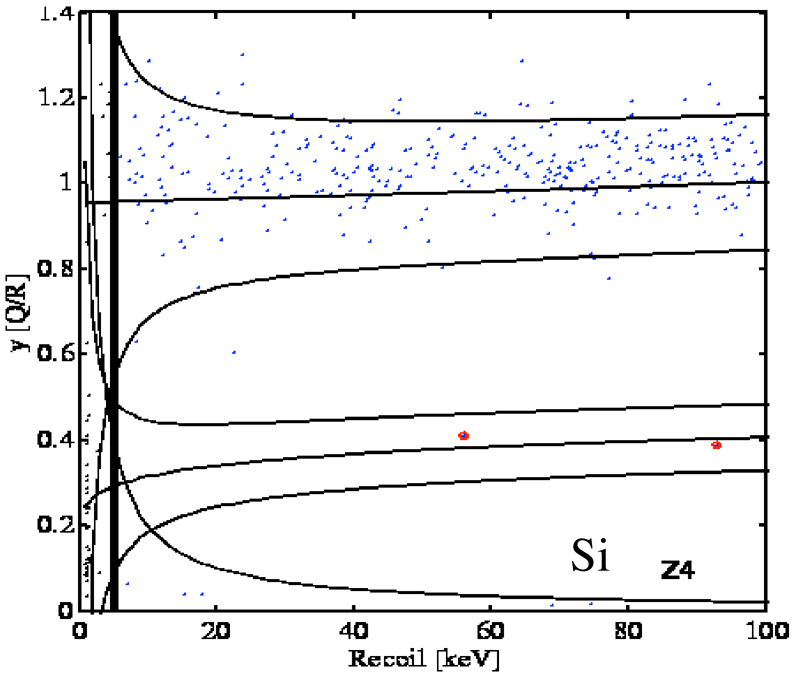
CDMS II Tower1 at SUF (3)

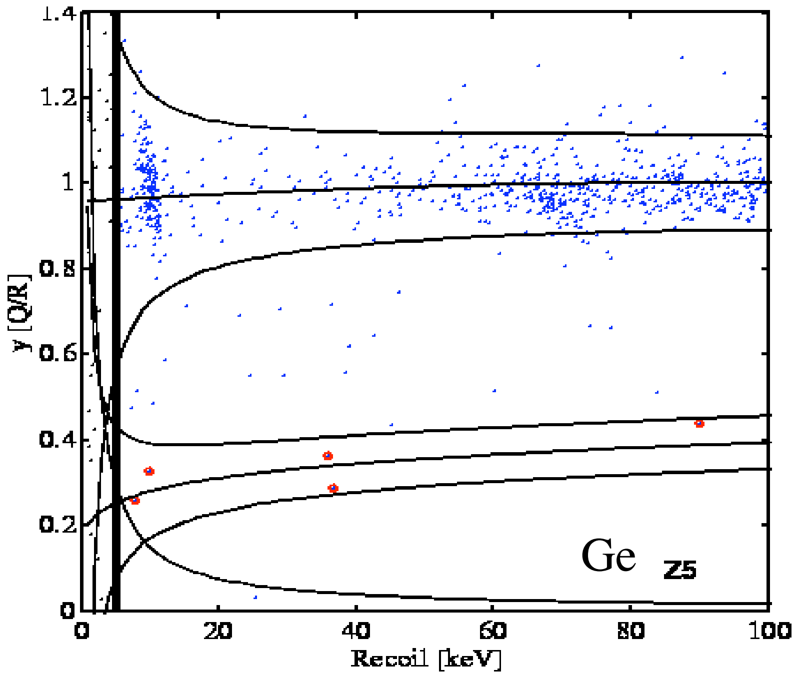
- –Muon Anti-Coincident Data
  - –Risetime cut
  - –Significant reduction of '*in between*' events
  - –Some reduction of nuclear recoil events (esp. at low energy)



CDMS II Tower1 at SUF (4)

- –Muon Anti-Coincident Data
  - –Ristime cut & **Single Scatter cut**
  - –All but a few events remain





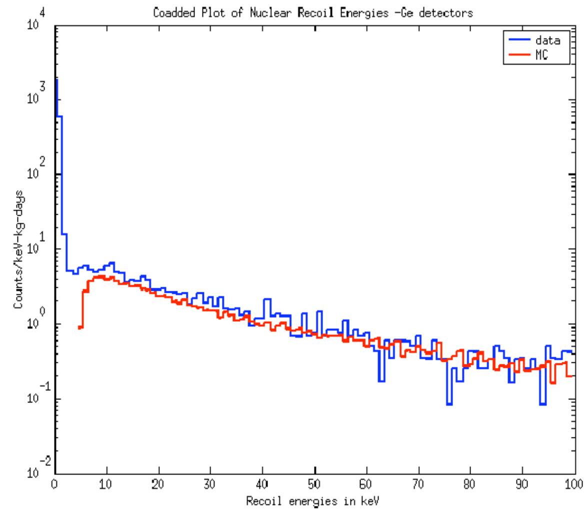
Check of Neutron Hypothesis

- **Muon-coincident (internal) neutron rate has dropped by ~ factor 3 due to this**
- **Muon-Anticoincident nuclear recoil candidate rate has also dropped by ~ factor 2-3, as predicted by MC**
- **Scaling MC under assumption of all nuclear recoil candidates in Run 19 being neutrons**
  - **Expect: 11.4 Gi Singles, 2 Si Singles, 4.7 doubles**
  - **Get: 18 Ge Singles, 2 Si Singles, 8 doubles**

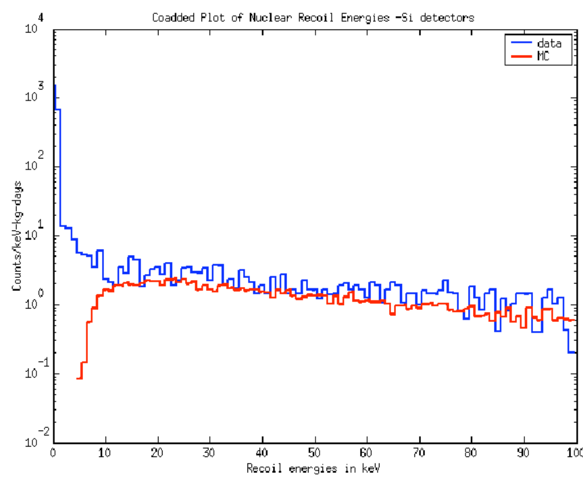
  in 5-100 keV range.
- **This confirms that most of the nuclear recoil candidates seen in Run 21 were indeed neutrons**

Monte Carlo of Mu-Coin Neutrons

Coadded spectra for the Ge detectors – Data vs MC



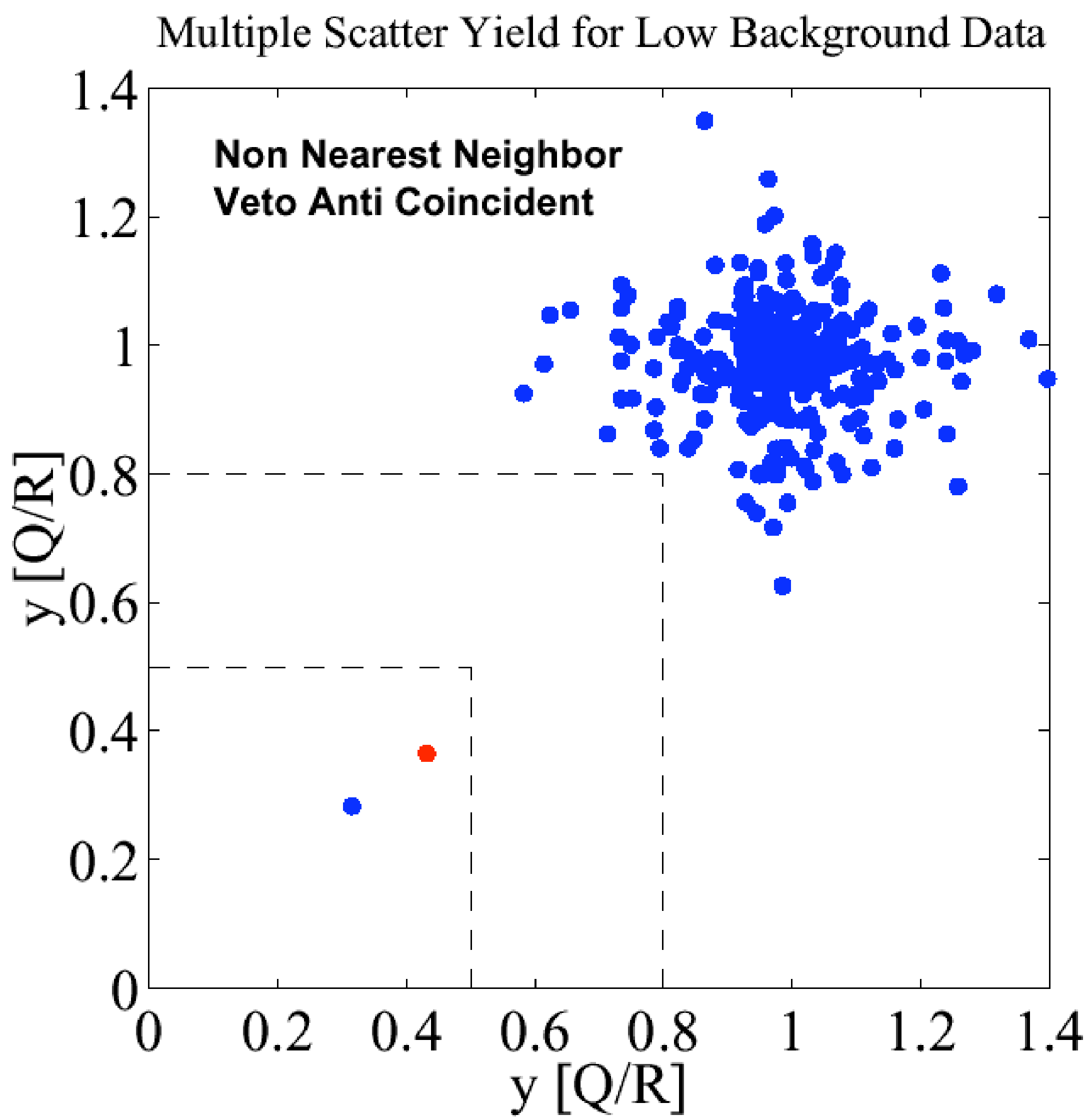
Coadded spectra for the Si detectors – Data vs MC



SUF 21: Multiple Scatters (non-nearest-neighbor)

- Very clean distinction between electron-recoil and nuclear-recoil events.
- No ‘surface’ betas scatter between non-neighbor detectors.
- Monte Carlo expected 2 neutron events, compared to 1(+1) seen in data.

(Event in red is tagged as a nuclear recoil in both detectors.)



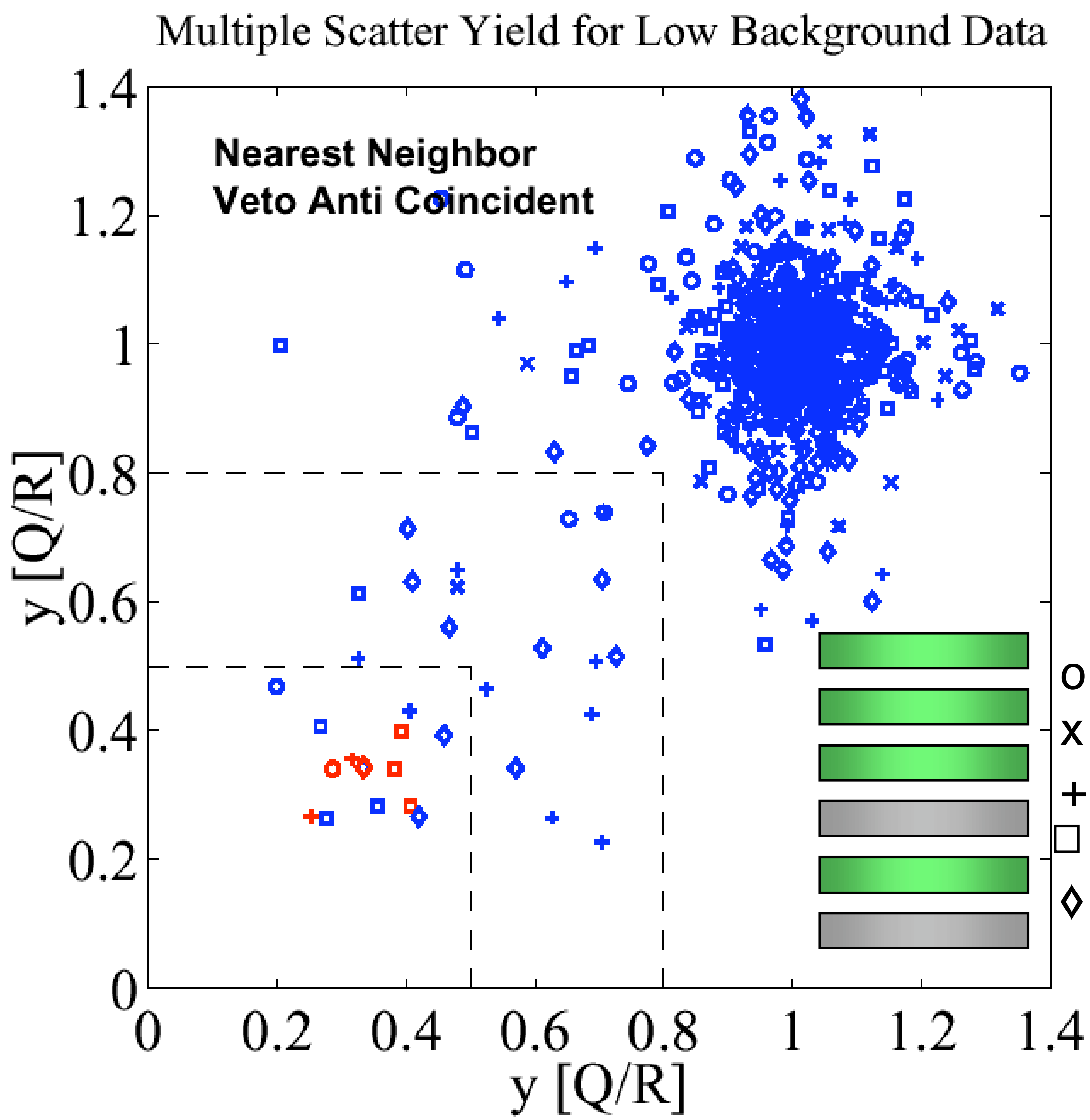
SUF 21: Multiple scatters (nearest-neighbor)

•Surface betas can scatter between neighboring detectors

•Bad-beta ‘blob’ not well defined; suspect beta-beta contamination of nuclear-recoil band.

•Expected only 3 neutron double scatters; see 7(+6).

(Events in red are tagged as nuclear recoils in both detectors.)



Status of Analysis

- The excess of singles (18 vs. 11.4) and multiples (8 vs. 4.7) may be due to surface electron contamination
- In order to do neutron "subtraction" conservatively, we need to estimate surface electron leakage into
  - Multiple scatters
  - Si singles

  Otherwise, we will "subtract" too many
- Analysis efforts currently focused on on these fronts
- Therefore, we presently have a "no-subtraction" upper limit and an "expected-with-subtraction" upper limit
- 6V data to be analyzed soon

SUF 21: Expected WIMP sensitivity

- The excess of singles (18 vs. 11.4) and multiples (8 vs. 4.7) may be due to surface electron contamination
- In order to do neutron "subtraction" conservatively, we need to estimate surface electron leakage into
  - Multiple scatters
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  Otherwise, we will "subtract" too many
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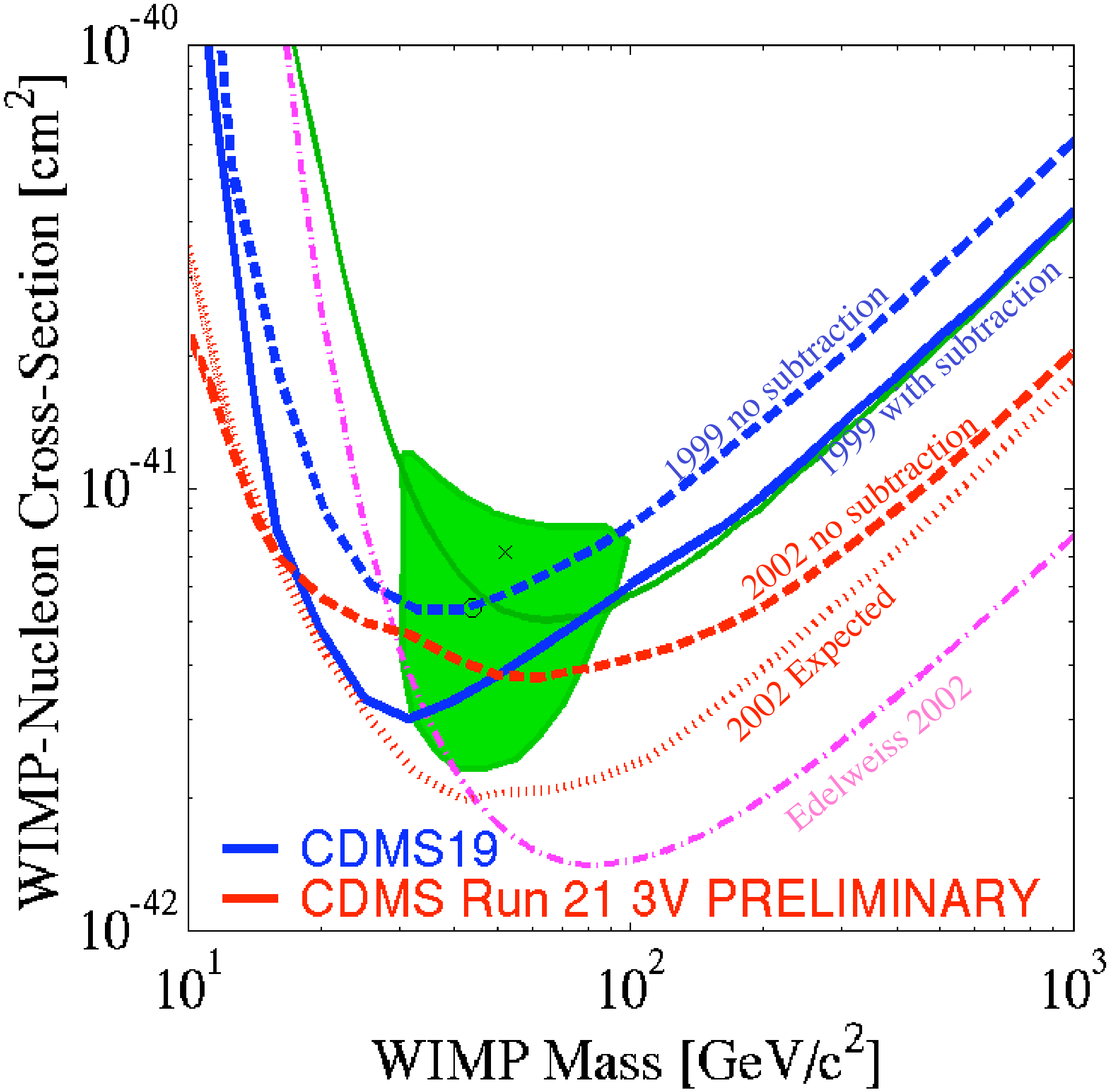


Summary

1. CDMS I is reaching sensitivity limit due to shallow site. The latest data confirms that neutrons are dominant background.

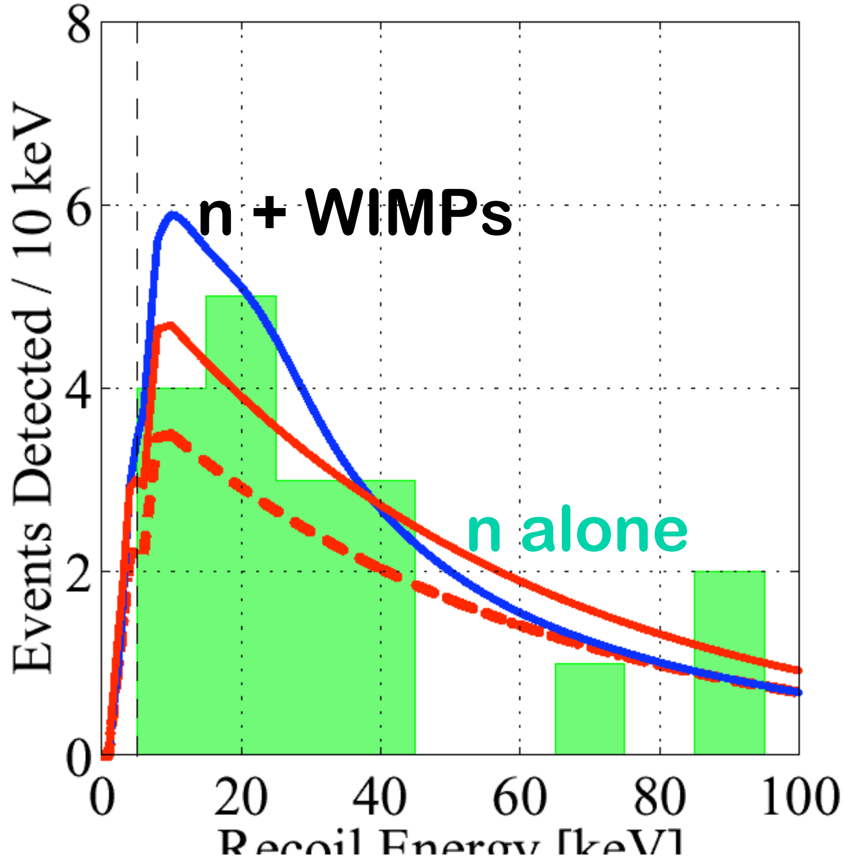
2. CDMS II can achieve much higher sensitivity in short time.

3. However, delays in installation of cryogenic component has pushed the commissioning date to January 2003.

4. Good News: Data from the first tower to be run in CDMSII is very is encouraging with regard detector performance and intrinsic backgrounds

More Slides

Energy Spectrum of WIMP candidates



- For our current 3V data, best fit to likelihood is with 17 neutron singles (red dashed curve) plus 7 events from 43-GeV WIMP (blue curve for total)
- Best fit neutron-only spectrum also shown (red solid curve)
- Need WIMPs (or other contamination, or different efficiency) to make spectrum fit well
  - Check efficiencies (Sharmila)
  - Estimate contamination (Vuk)

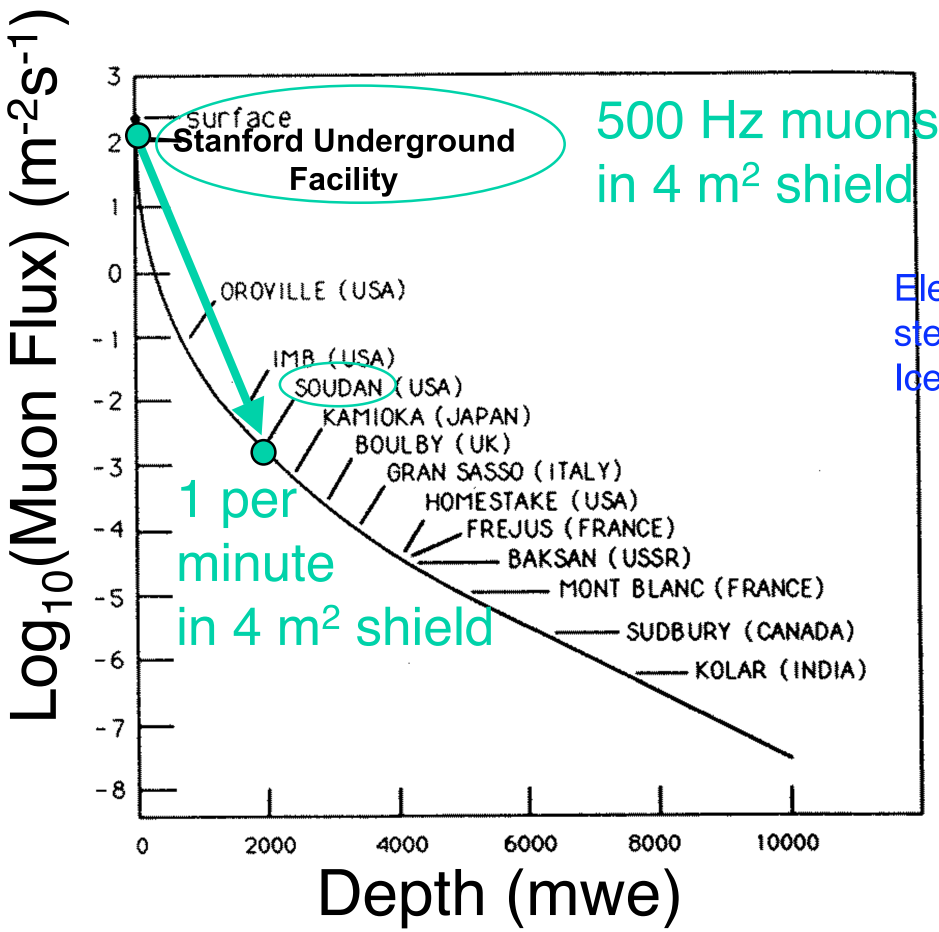
Detector Performance

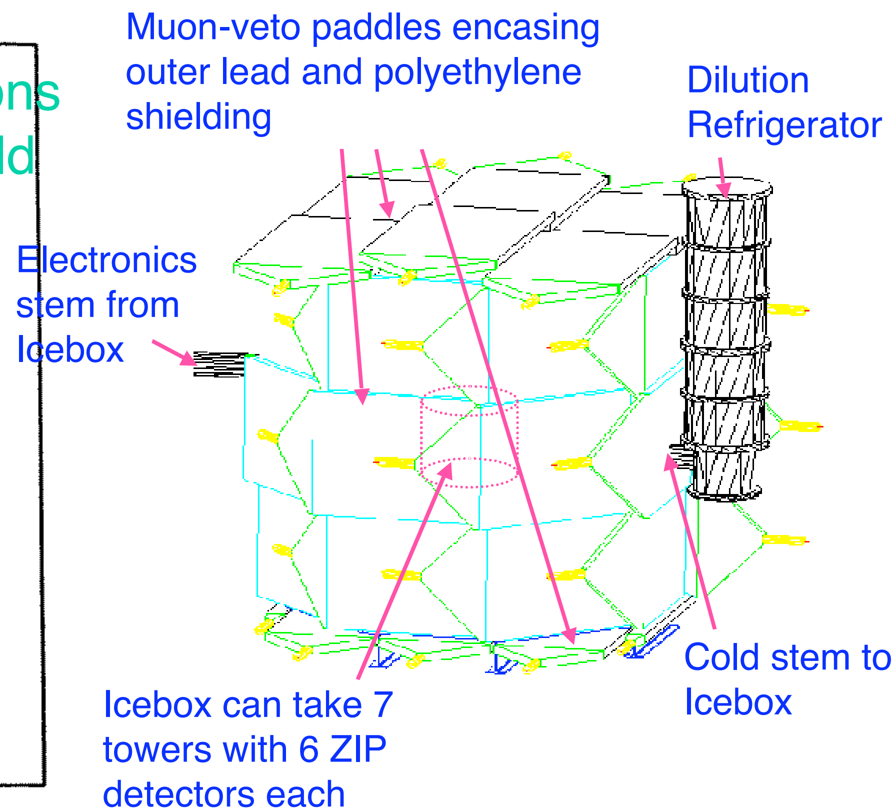
- Backgrounds
  - Bulk electron recoil (mainly photon) rate ~ 1/keV/kg/day @ 20 keV
  - Surface electron rate ~ 0.2 /keV/kg/day @ 20 keV
  - Both rates are likely dominated by cosmogenic activation of near-detector material at shallow site
  - No red flags in terms of detector contamination

- Performance
  - 100% efficiency at 5 keV Recoil energy
  - Phonon baseline FWHM resolution ~ 320 eV
  - Ionization baseline FWHM resolution ~ 1 keV
  - Bulk electron recoil rejection efficiency > 99.99% (proposal: 99.5%)
  - Surface electron rejection efficiency > 95% (proposal: 95%)

CDMS II at Soudan

Depth of 2000 mwe reduces neutron background from ~1 / kg / day to ~1 / kg / year

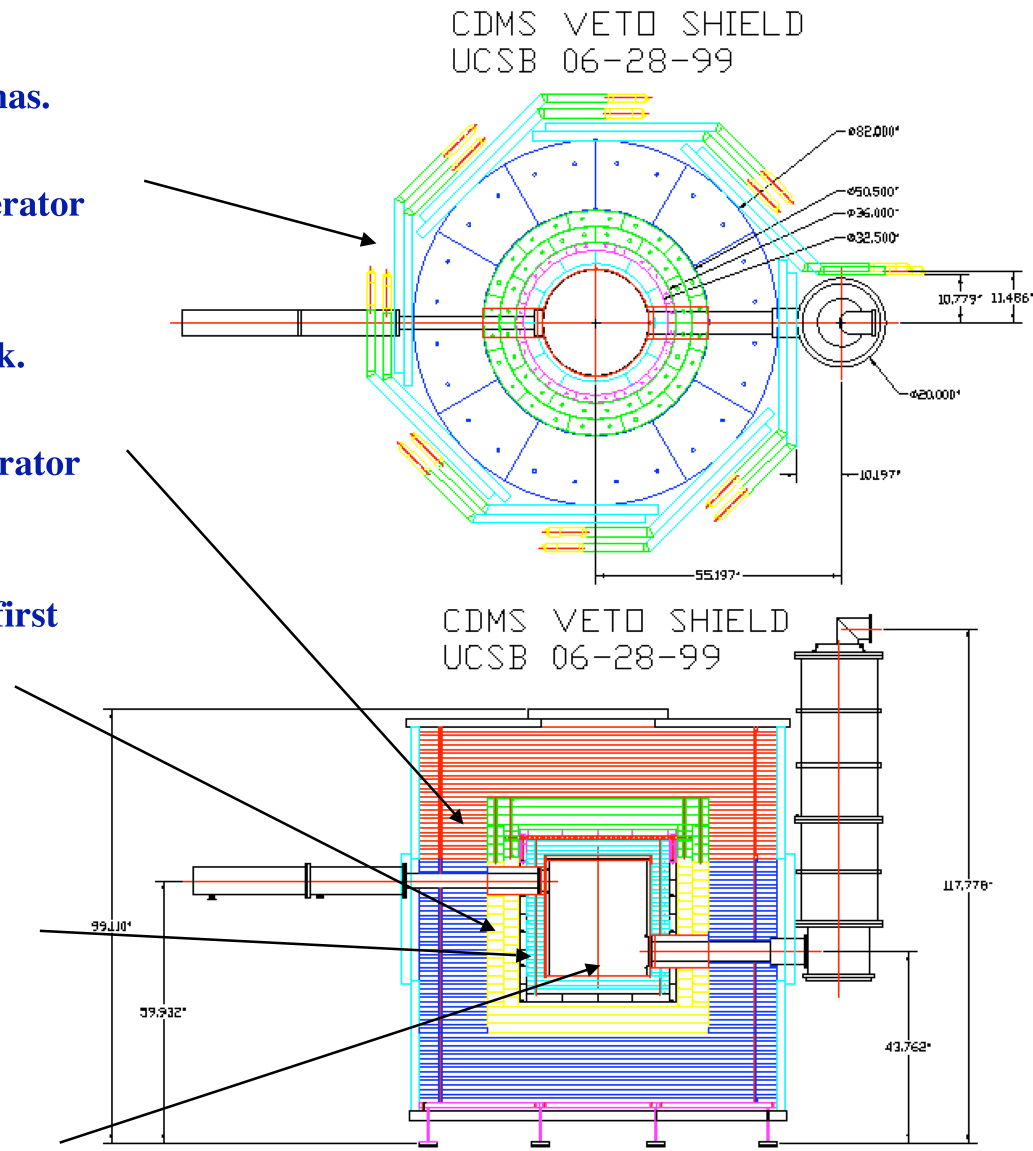




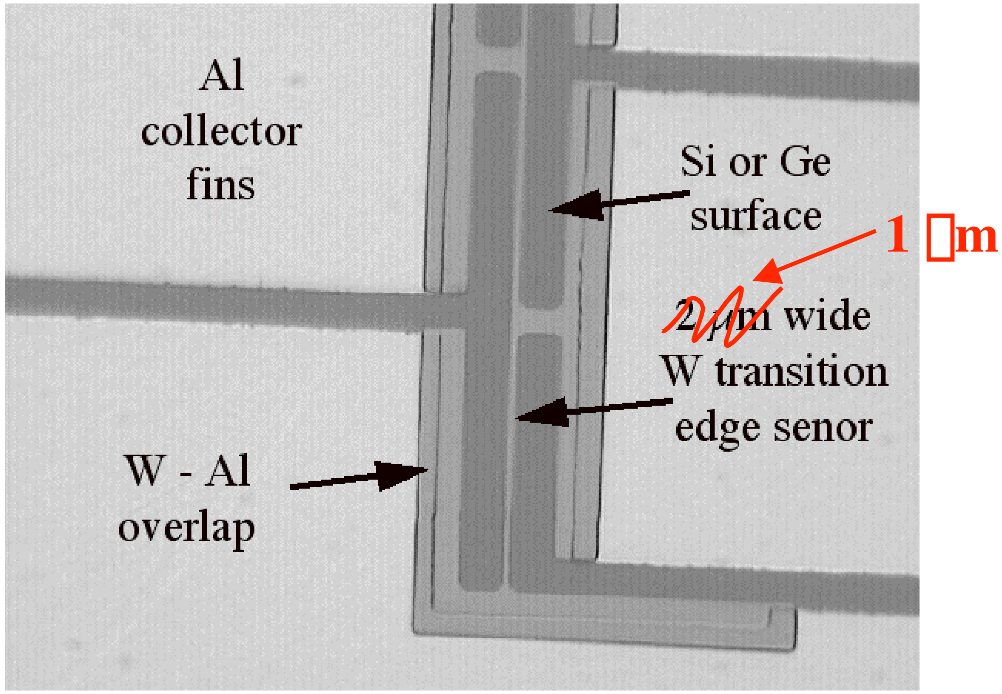
Experimental apparatus

CDMS II at Soudan - shielding

- **Muon veto paddles can discriminate between muons and high energy gammas.**
- **Outermost polyethylene neutron moderator is 41 cm thick.**
- **Outer lead gamma shield is 23 cm thick.**
- **Secondary polyethylene neutron moderator is 14 cm thick.**
- **Icebox inner shield(s) optimized after first runs.**



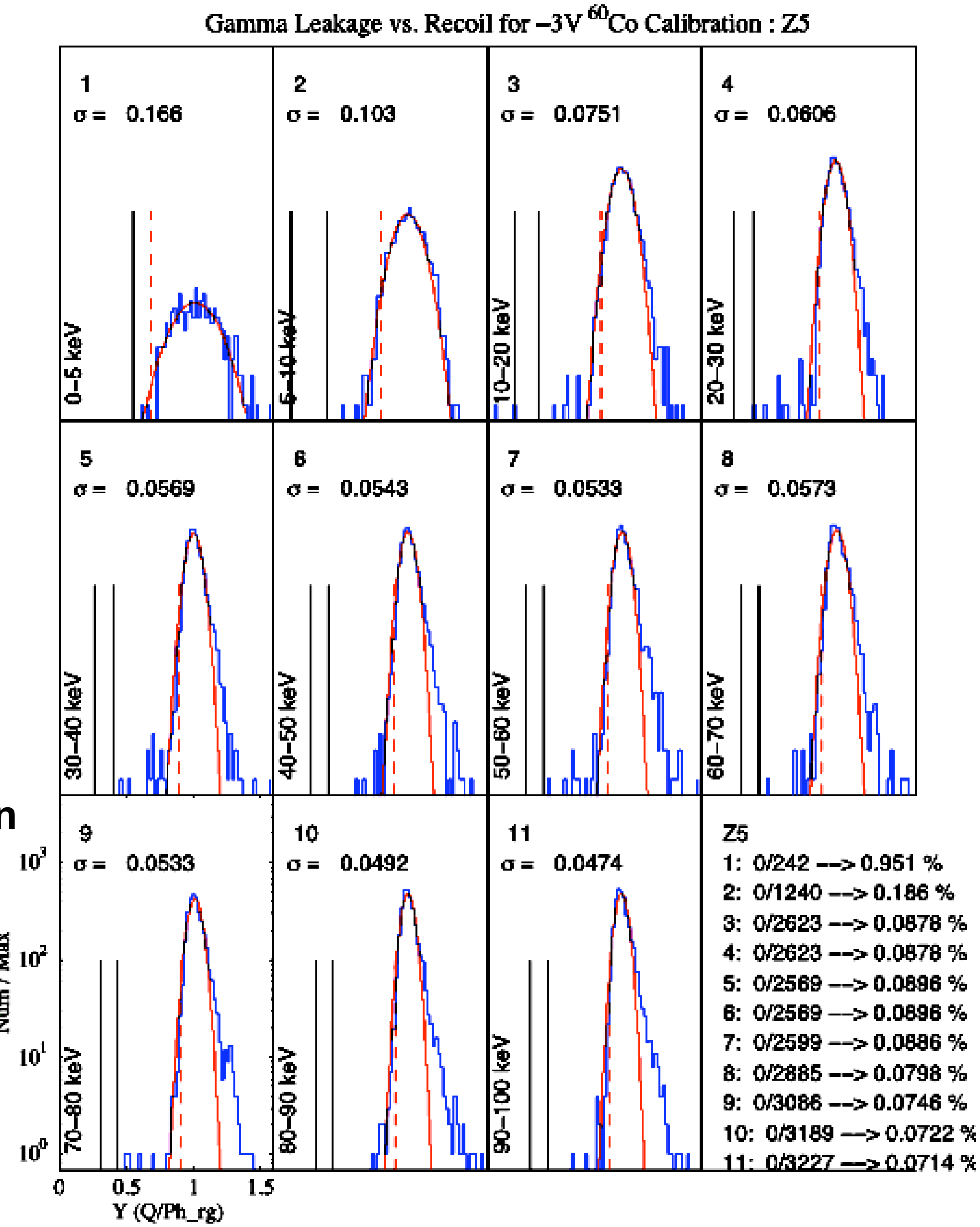
The CDMS ZIP Detectors

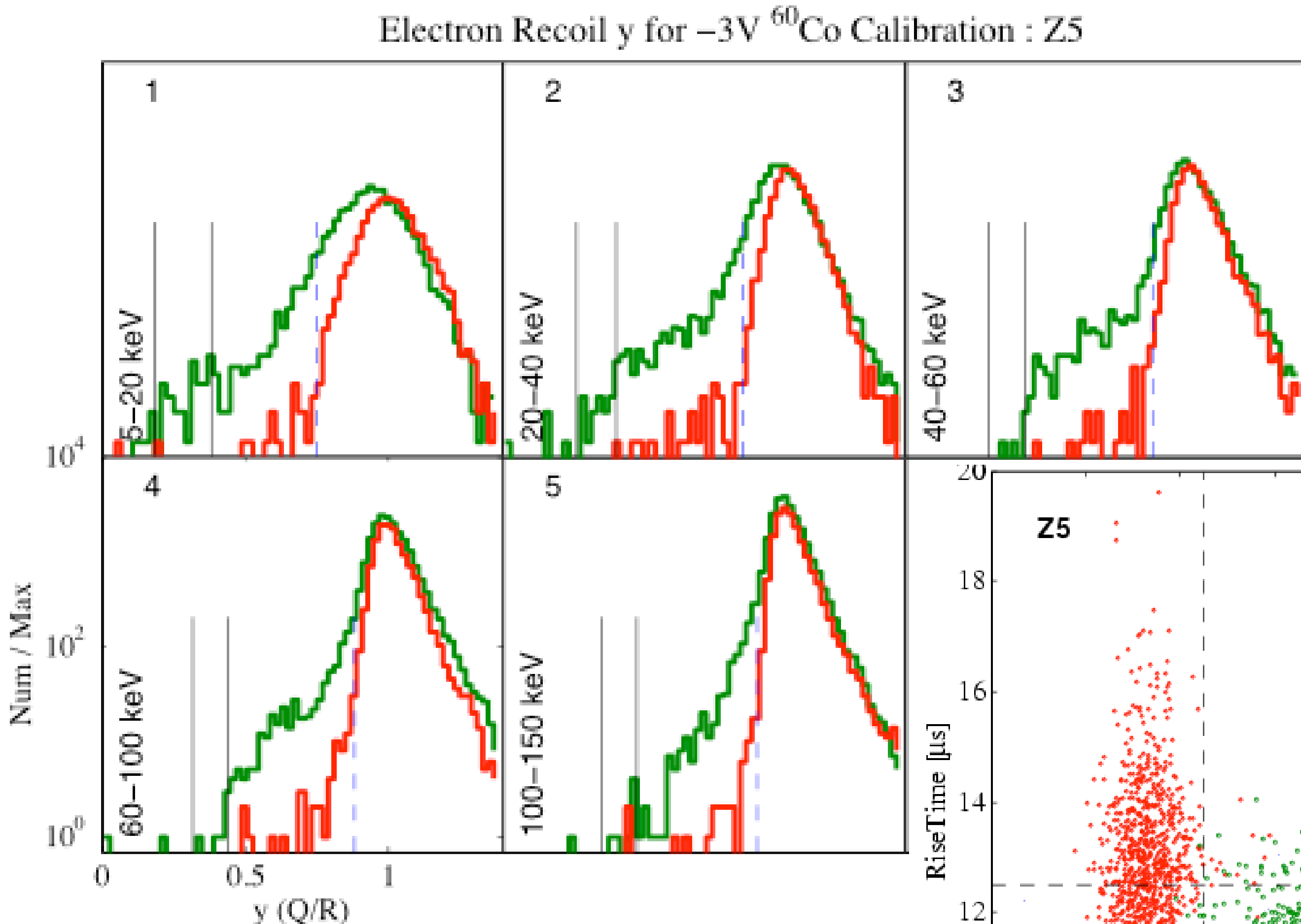


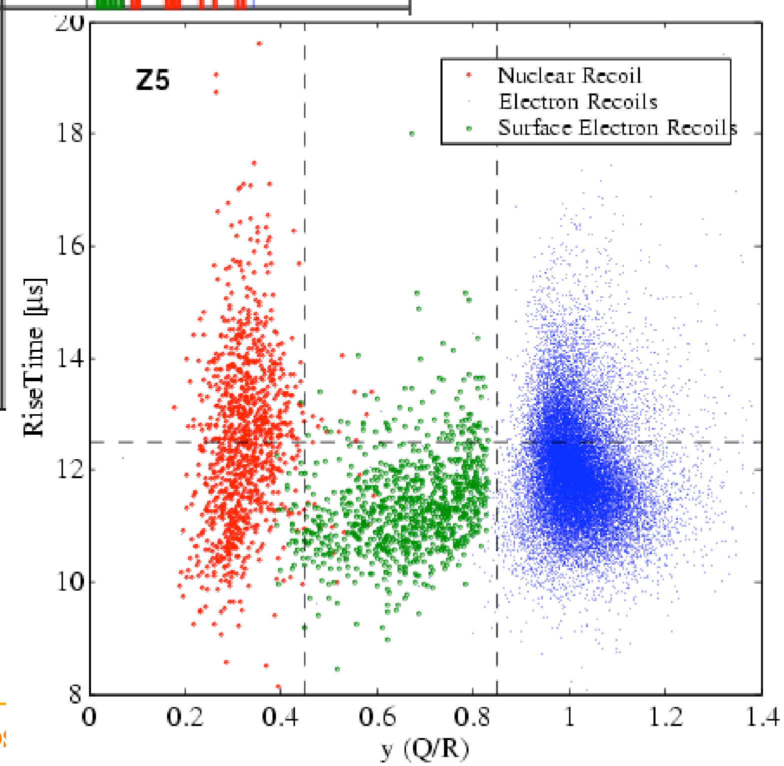
Z-dependent Ionization &
Phonon Detectors

Photon Rejection with ZIPs

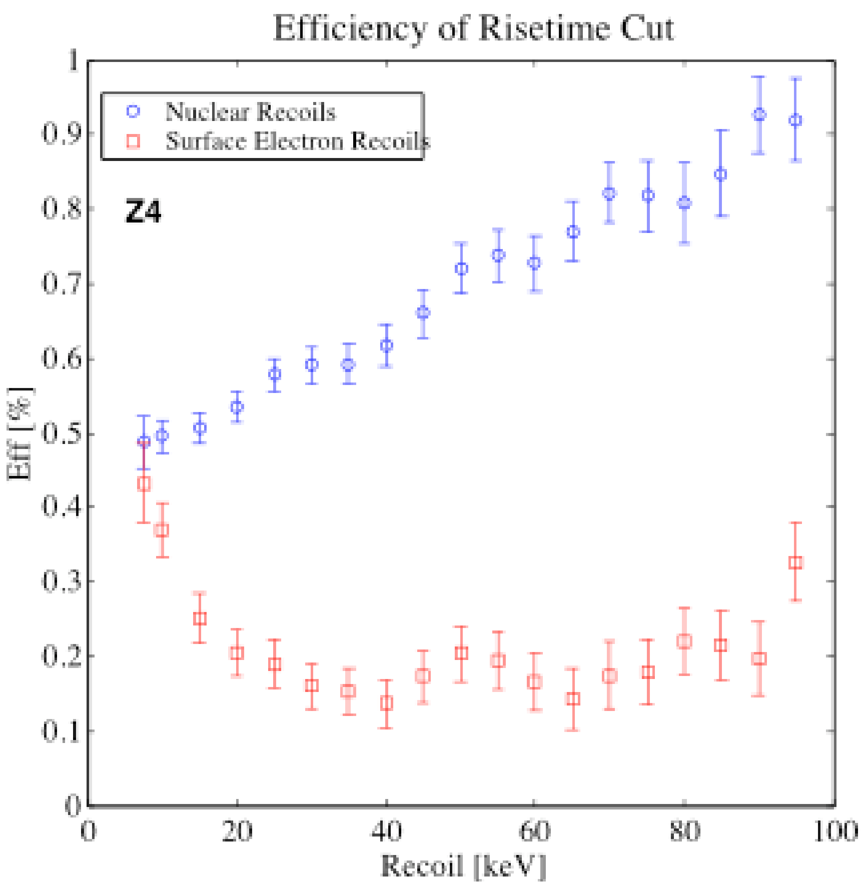
- Histogram of ionization yield as a function of energy for *in-situ* photon calibration at SUF
- No events leaked into the nuclear recoil acceptance region in detector Z5
  - **Photon rejection** > 99.99% (0/26610) **for** 5-100 keV **range**
    - Equivalent to 5 years of background operation at 0.8 events/keV/kg/day
  - **Photon rejection** > 99.9% (0/3863) **for** 5-20 keV **range**
    - 5x better performance than specified in CDMS II proposal
  - Other detectors display similar performance with only a few events out of ~ 25000 leaking into the nuclear acceptance region

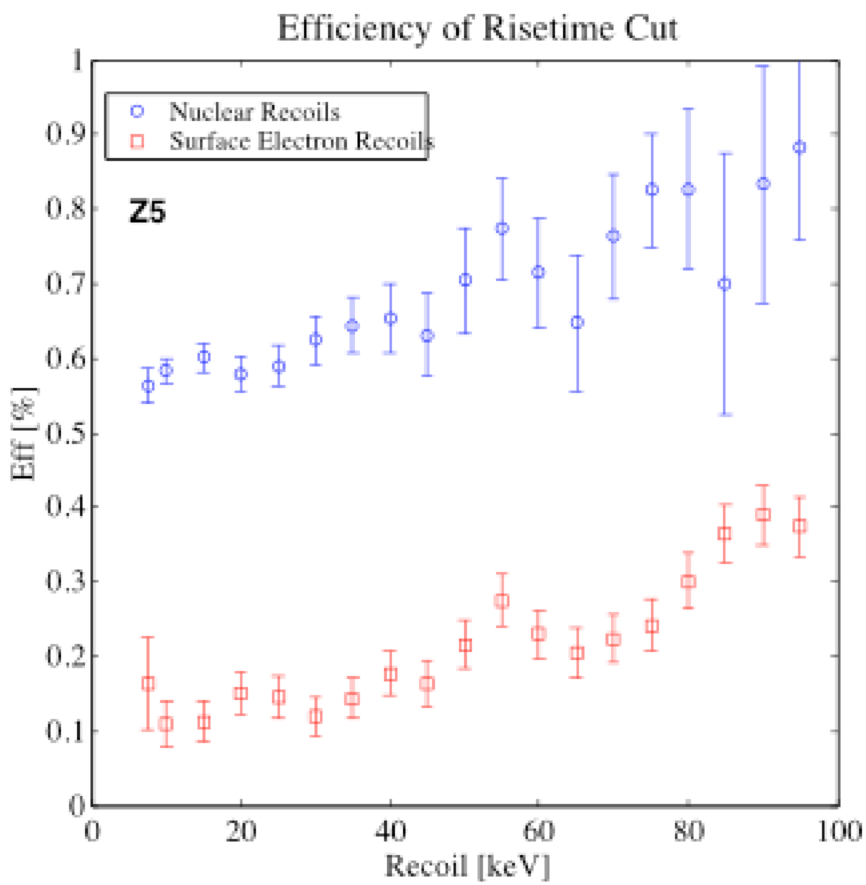



Electron Recoil y for −3V ^{60}Co Calibration : Z5
1
2
3
4
5
5–20 keV
20–40 keV
40–60 keV
60–100 keV
100–150 keV
Num / Max
10^4
10^2
10^0
0
0.5
1
y (Q/R)


Z5
Nuclear Recoil
Electron Recoils
Surface Electron Recoils
RiseTime [µs]
y (Q/R)
20
18
16
14
12
10
8
0
0.2
0.4
0.6
0.8
1
1.2
1.4

Efficiency of Risetime Cut





Time Line of the SUF Run

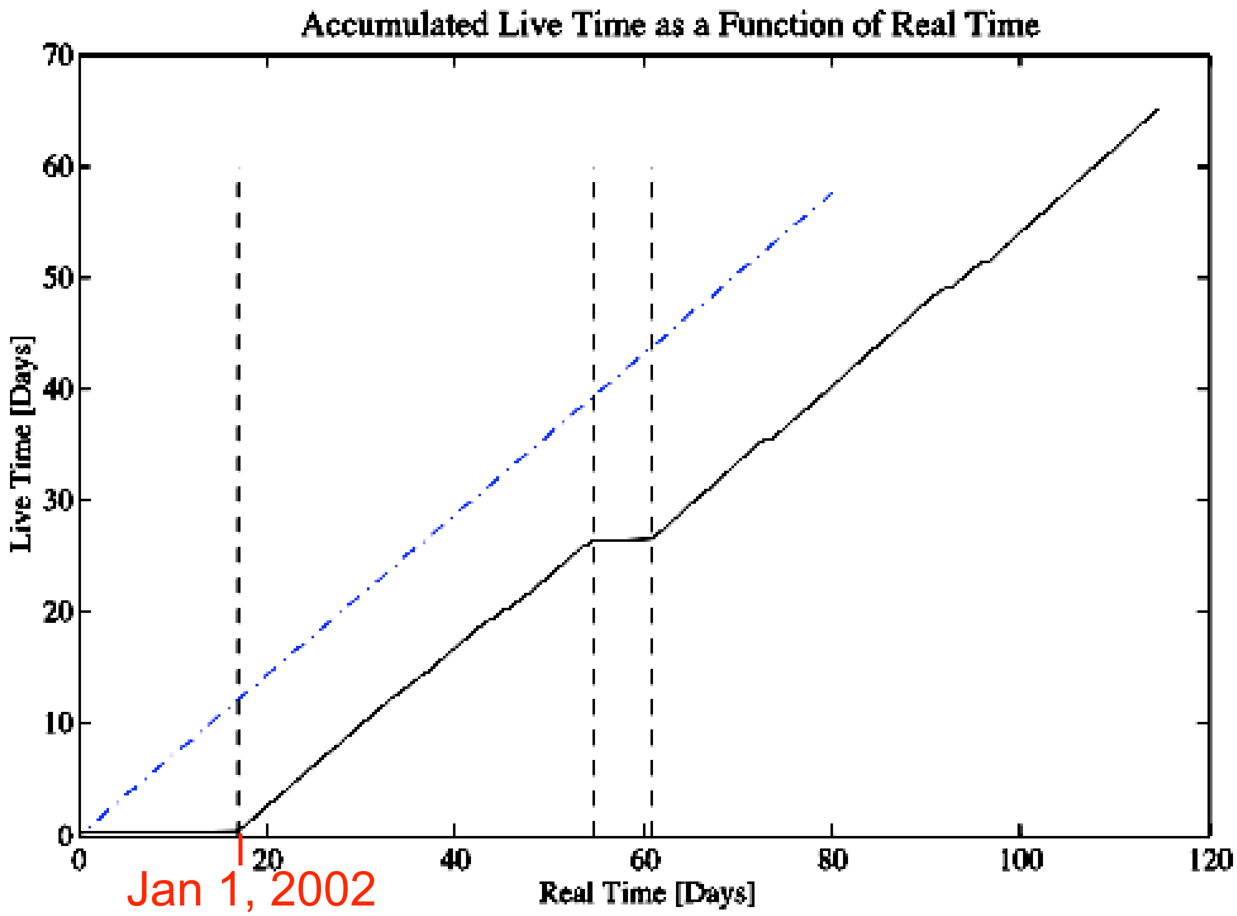
Data Run from Dec 2001 - June 2002

Data is accumulated at a rate of ~ 0.75 liveday/real day

- Cryogen fills
- DAQ livetime
- LED flashing

3V data set ~ 90 real days

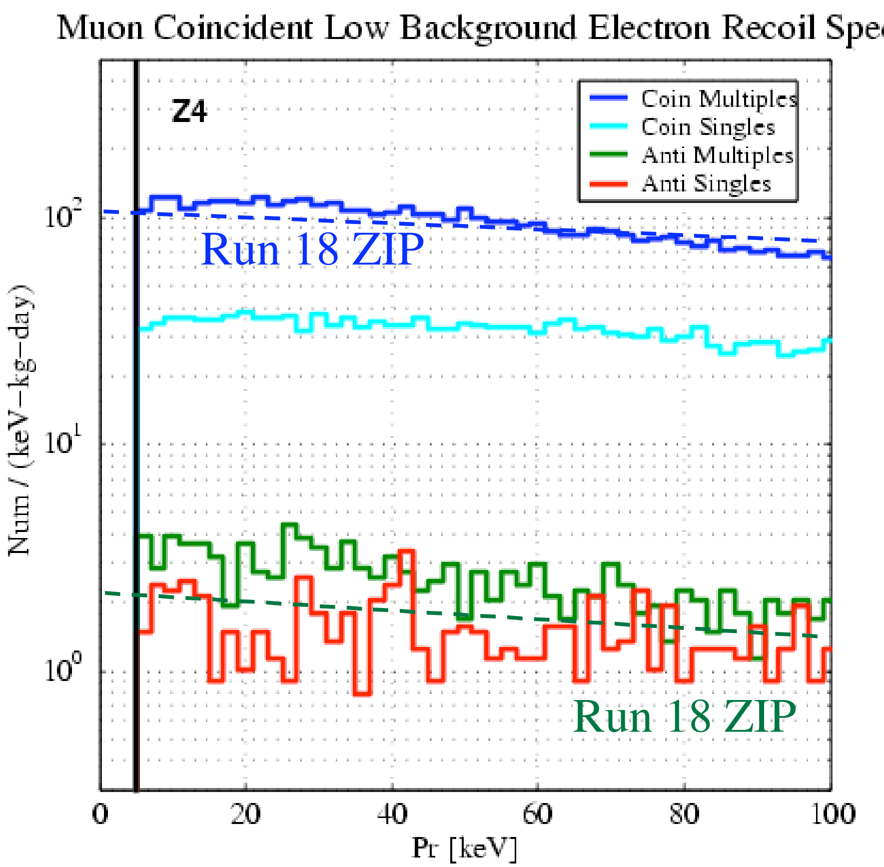
- 65 live days
- 4.5 million events
- 4 Ge ZIPs 0.250 kg ea.
- 2 Si ZIPs 0.100 kg ea.

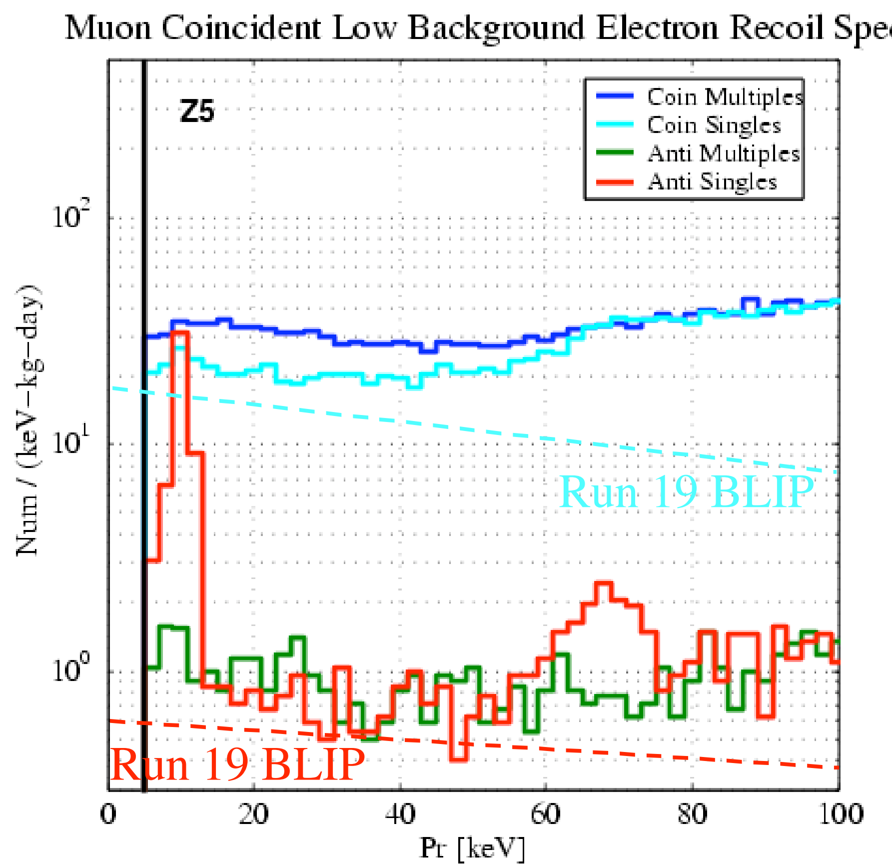


Photon Rates

Photon background rate ~ 1 evt/keV/kg/day in Ge and
~ 3 evt/keV/kg/day in Si

– With a discrimination ability of > 99.8% the gamma background is reduced to < 2*10^{-3} evt/keV/kg/day





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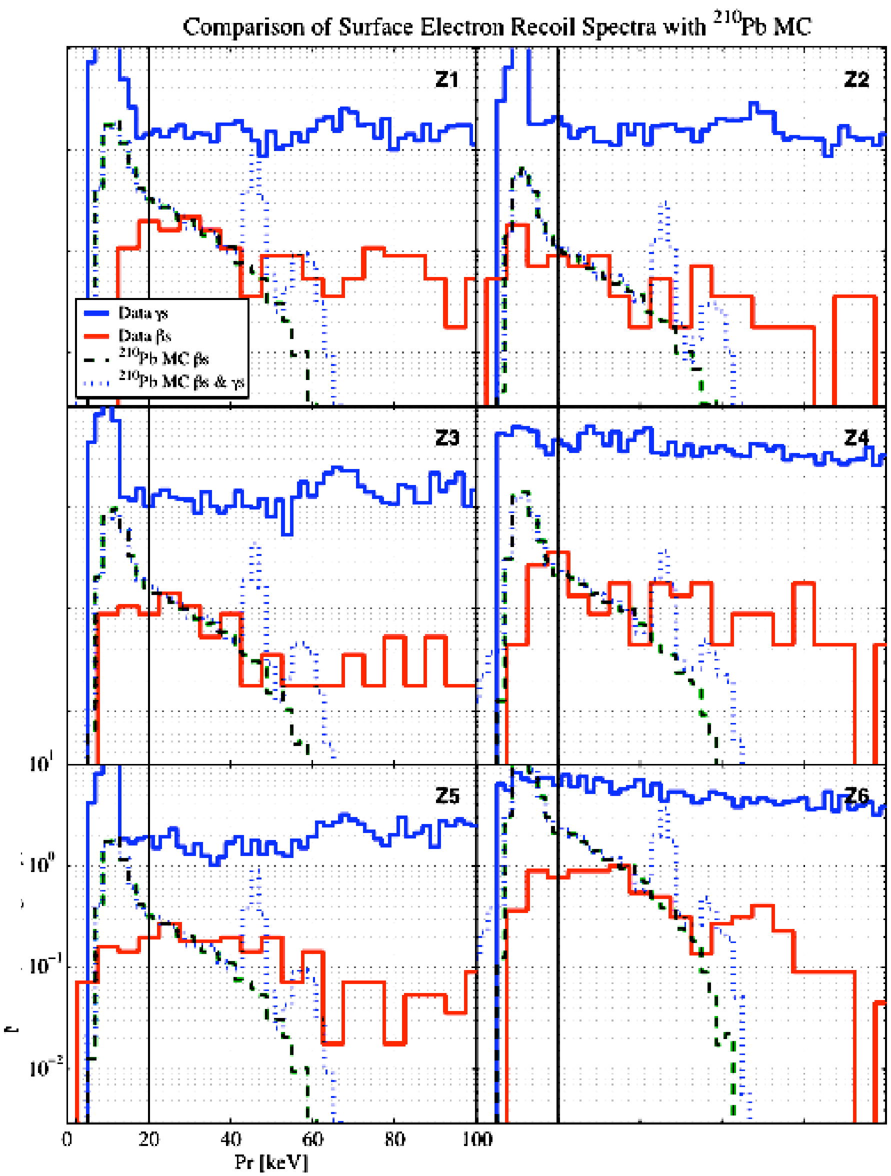
MonteCarlo Simulation of ^{210}Pb Contamination

- Limits on ^{210}Pb contamination can also be determined by comparing MC of ^{210}Pb decays to rate of s seen in the data
- Limits also determined by calculating exposure of detectors to environmental ^{222}Rn prior to the Run
- Estimates comparable with those derived from the rate of particles



Final Data from 1999

1999: 4x165g Ge BLIP (15.8 kg days after cuts)

- 23 single scatter nuclear recoils (1.5/kg/day)
- 4 multiple scatter nuclear recoils (0.25/kg/day)

1998 100 g Si ZIP (1.6 kg days after cuts)

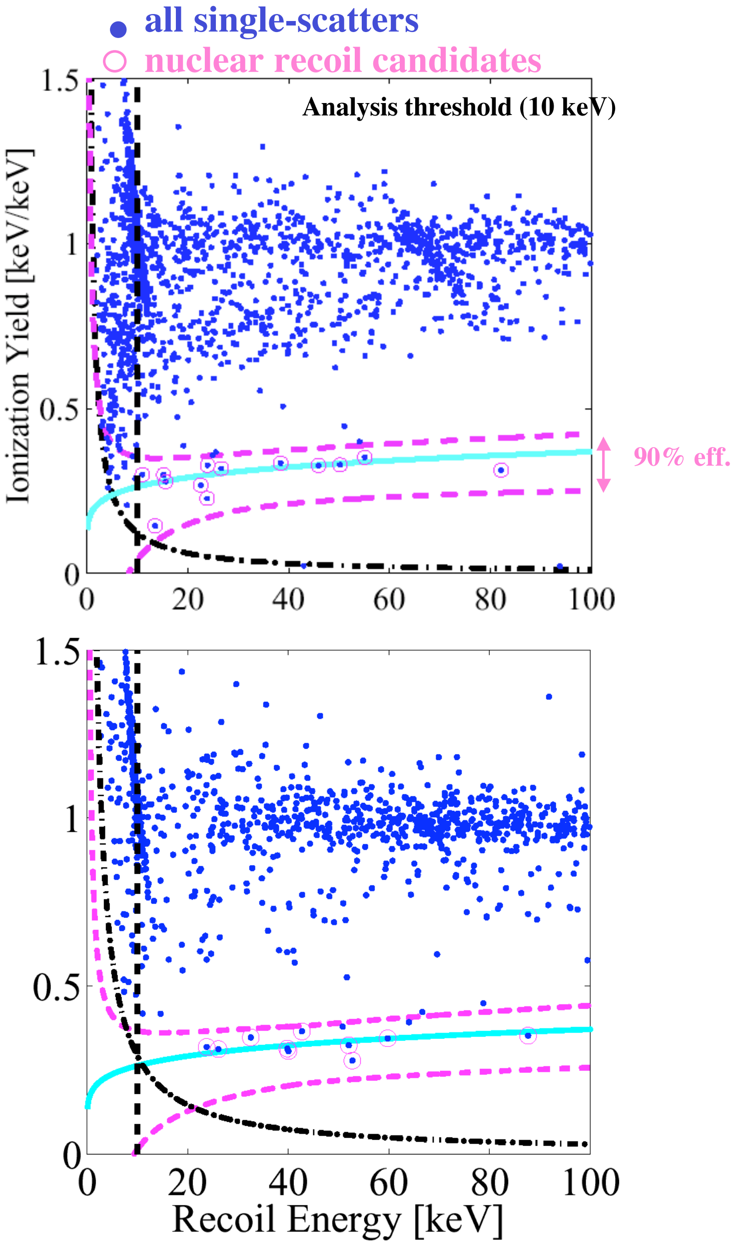
- 4 single scatter nuclear recoils (2.5/kg/day)

Results consistent with neutrons

- 4 multiple scatters is direct evidence of neutron background.
- WIMP interaction rate in kg of Si is x6 lower than in Ge. So Ge/Si numbers inconsistent with WIMPs.
- Neutron interaction rate in kg of Si is x2 higher for Si than in Ge. Ge/Si consistent with neutrons.
- Beta events well separated from nuclear recoil band.

Is there a neutron background with this rate?

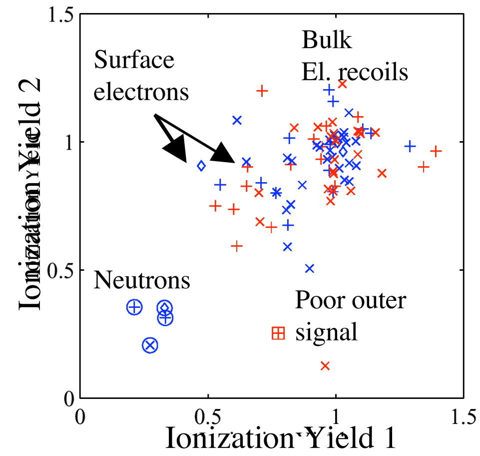
- Yes. MC of muon-induced high-energy neutrons from rock yields similar rates.

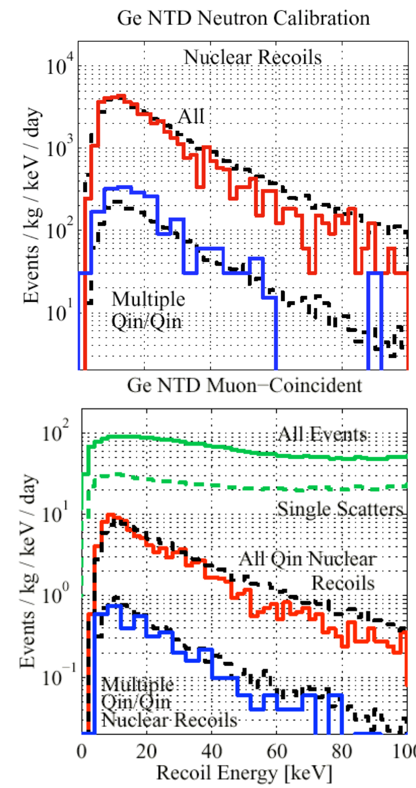


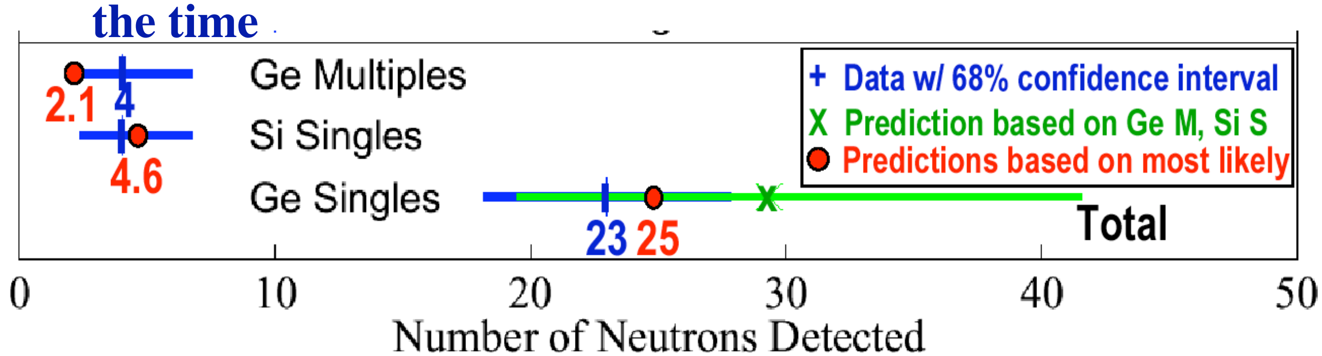
Neutron Interpretation

- Neutron multiple scatters are free of contamination
- Monte Carlo: Use 4 Ge multiple scatters and 4 Si single scatters to estimate neutron contribution to 23 Ge single scatters. MC prediction of absolute neutron rate not used due to high uncertainty. Only ratios used.
- MC predictions reliable: based on checks against data for neutron calibration and veto-coincident neutrons

  Good agreement with no free parameters
- All single scatter nuclear recoils consistent with neutrons.
- Likelihood ratio test: Expect worse agreement 30% of the time

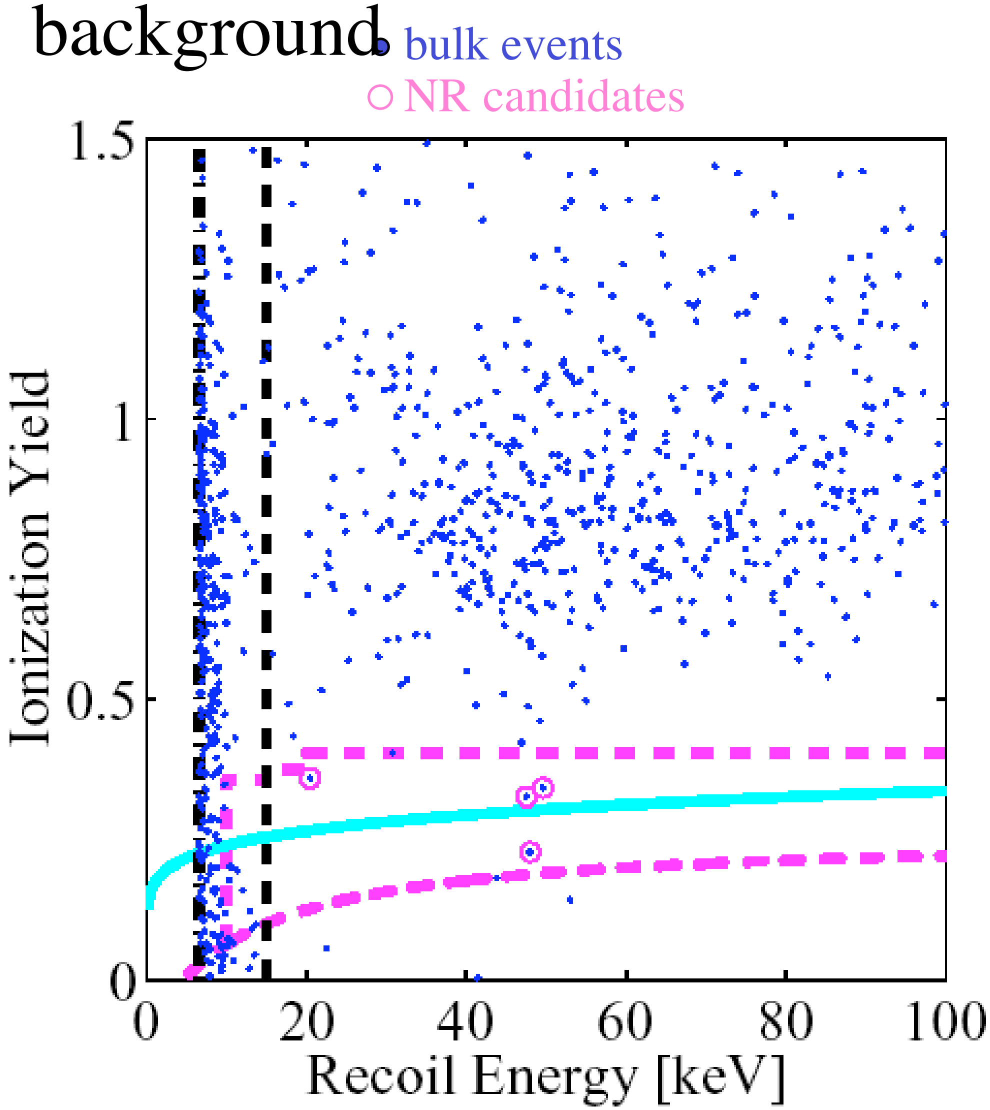






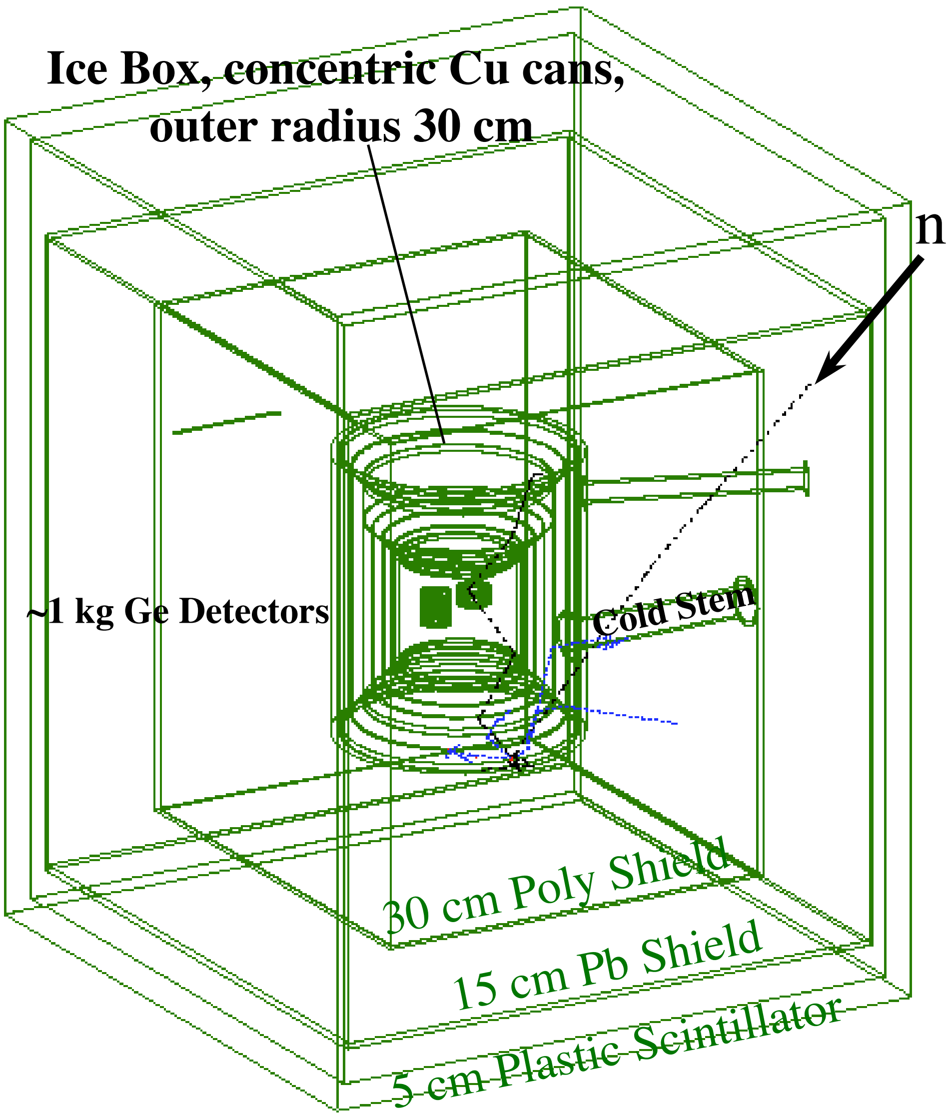
1998 Run Si ZIP Data Set

Early-design Si ZIP measured external neutron background



- **Not WIMPs: Si cross-section too low (~6x lower rate per kg than Ge)**
- **Misidentified electrons?**
  - **Calibration predicts < 0.26 events in 20-100 keV range at 90% CL, but we cannot rule out systematic error due to fact that conditions of calibration and low-background data-taking were different**
- **Using conservative assumptions about a calibration taken under same conditions as low-background data predicts contamination of 2.2 events in NR band (<7.3 events at 90% CL)**
- **Use this very conservative estimate (7.3 events) in calculating limits**

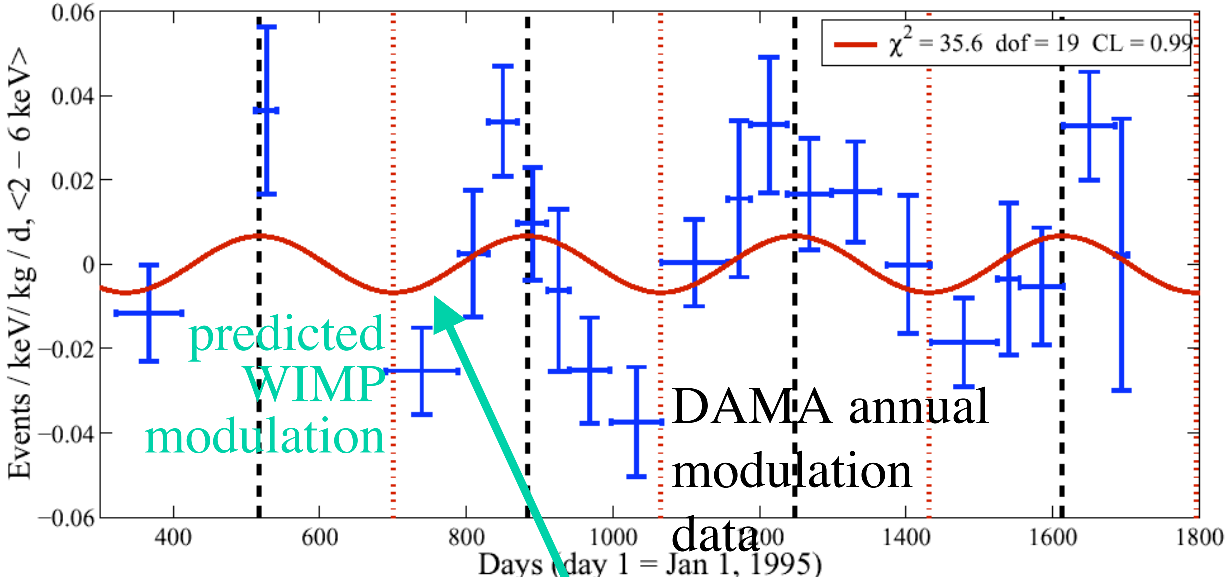
Neutrons from Rock



Dimensions give approximate radial thickness of layers

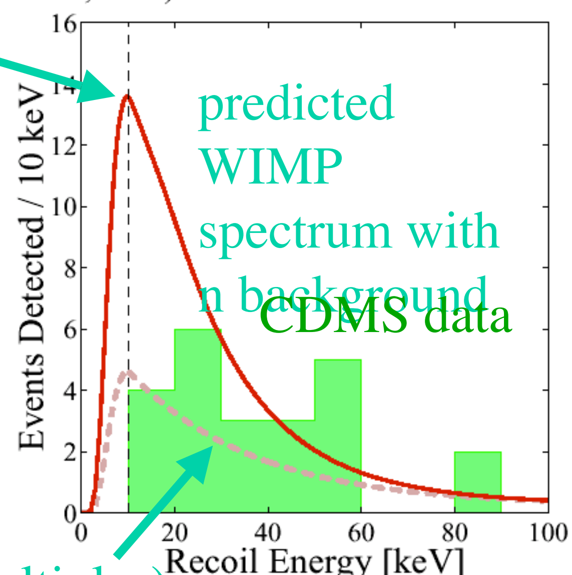
- Hadron cascades from high energy muon-nuclear interactions give neutrons of high energy.
- Neutrons with E > 50 MeV penetrate polyethylene shield. Afterwards, they scatter in copper cans producing low energy secondary neutrons (mostly < 20 MeV). These scatter in detectors.
- Rate from literature is in right range. But has x4 uncertainty for 17 m.w.e.
- Monte Carlo simulations of muon induced hadron cascades yields neutron rate x3 higher than observed veto-anticoincident nuclear recoils.
- Probably due to vetoing of associated muons and hadrons (expect 40% rejection just from neutron interactions in scintillator).
- Continuing simulations to establish vetoed fraction and identify such events in data

Compatibility of CDMS and DAMA

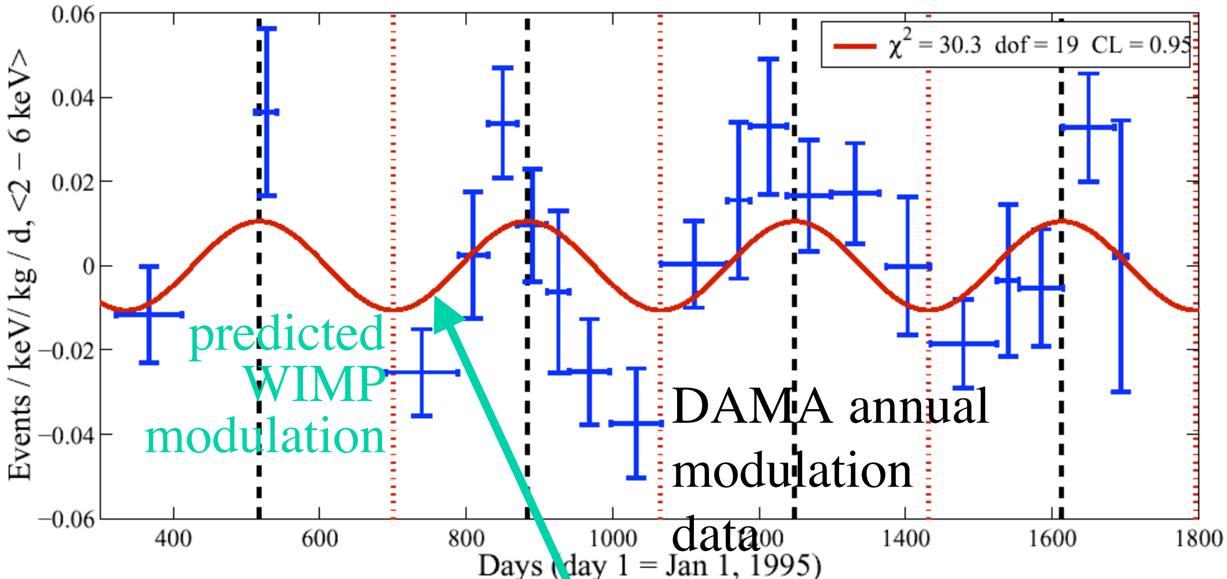


- **Likelihood ratio test**
  - **asymptotic approximations**
  - **“standard” halo**
  - **standard WIMP interactions**
- **CDMS results incompatible with DAMA model-independent annual-modulation data (left) at > 99.99% CL**

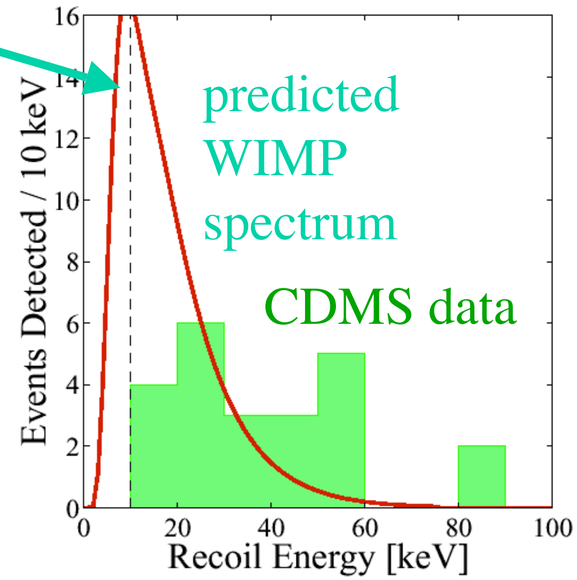
Best simultaneous fit to CDMS and DAMA predicts too little annual modulation in DAMA, too many events in CDMS (even for small neutron background)



Compatibility of CDMS and DAMA



Best simultaneous fit to CDMS and DAMA predicts too little annual modulation in DAMA, too many events in CDMS (even for NO neutron background)



- **Likelihood ratio test**
  - **asymptotic approximations**
  - **“standard” halo**
  - **standard WIMP interactions**
- **CDMS results incompatible with DAMA model-independent annual-modulation data (left) at > 99.8% CL, even under assumption that none of the CDMS events are neutrons**